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ASTRONAUTICS INFORMATION

ELECTRIC PROPULSION

LITERATURE SEARCH NO. 587

JUNE 1964

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

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ASTRONAUTICS INFORMATION

ELECTRIC PROPULSION

LITERATURE SEARCH NO. 587

**COMPILED BY
JUDITH HAYES**

**JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
JUNE 1964**

FOREWORD

This Literature Search has been compiled to update and supplement Astronautics Information Literature Search No. 428, "Electrically Propelled Spacecraft and Associated Subjects," May 1962. It has been prepared at the request of the technical staff of the Jet Propulsion Laboratory and is published for distribution to interested organizations working in the field of astronautics.

Five broad subject categories are employed to classify the references as **General**, comprising basic research and comparative studies of the types of propulsion covered in the other four Sections: **Electromagnetic**, **Electrostatic**, **Electrothermal**, and **Nuclear-Electric** (systems which utilize nuclear power to drive electric engines). Within each Section, references are arranged in chronological order. Additional references obtained during manuscript processing are contained in an **Addenda**. An Author Index and Corporate Source Index are included.

The following sources were consulted in the preparation of this document:

Defense Documentation Center and Armed Services Technical Information Agency TABS, June 1962–December 1963

Applied Science and Technology Index (AS&T), April 1962–December 1963

Astronautics Information Abstracts (AI/A), April 1962–August 1963

Astronautics Information Survey (AI/S), April–June 1962

Electrical Engineering Abstracts (EEA), 1962–1963

Engineering Index (EI), 1961–1963

International Aerospace Abstracts (IAA), January–December 1963

Scientific and Technical Aerospace Reports (STAR), January–December 1963

Technical Publications Announcements—NASA (TPA), January–December 1962

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GENERAL*

1. AIRCRAFT AND SPACECRAFT PROPULSION

Rothrock, A. M. (National Aeronautics and Space Administration, Washington, D.C.)
Canadian Aeronautical Journal, v. 5, no. 5, pp. 172-183,
May 1959

The energy sources, propellants, and propulsion systems for aircraft and spacecraft are reviewed to coordinate and organize research efforts. At supersonic speeds up to Mach 3, the turbojet engine, with or without afterburner, is predominant. However, at flight speeds above Mach 3, more research effort is needed to determine whether a ramjet or a combination turbojet and ramjet is the propulsion system required. This review indicates that until research on nuclear devices leads to practical engineering applications, the chemical thermal rocket is still the most frequently used device for space flight. A preference for liquid propellants over solid propellants for space propulsion, except for smaller upper stages, is indicated. (TPA, 1962, N62-10168)

2. MISSION ANALYSIS FOR ELECTRIC PROPULSION SYSTEMS

June 1960
Thompson Ramo Wooldridge, Inc., Cleveland, Ohio
Engineering Report 4114, Final Report for July 1959-June 1960, WADD TR 60-533, AF 33(616)-5919
AD-292,241

Regions of applicability of electric propulsion systems were studied. Various missions were examined, and the performance available from electric propulsion systems was compared to that available from chemical systems. New methods for calculating both continuous and impulsive thrust requirements have been generated. The influence of Earth oblateness, lunar attraction, and other perturbations affecting the orbital plane of a satellite have been considered. The study has determined the thrust requirements for coplanar orbital transfer, change of orbital inclination, rotation of the line of nodes, and change of orbital eccentricity. The capabilities of electric propulsion systems for establishing the stationary orbit and an orbit that is continuously exposed to the Sun, and for accomplishing lunar, Mars, and Venus missions have been delineated.

3. ANALYZING EXHAUST VELOCITY REQUIREMENTS FOR ELECTRICALLY POWERED ROCKETS

Halverson, W. D., Rosebrock, T. L.
General Motors Engineering Journal, v. 8, no. 2, pp. 16-22,
April-May-June 1961

A study to determine the exhaust velocity which would result in maximum payload mass fraction for possible combinations of vehicle characteristics and mission requirements

is reported. An equation giving optimum exhaust velocity was derived by maximizing the ratio of payload mass to take-off mass and used in the study of three rockets. Results of this study are presented. (EI, 1961)

4. ELECTRIC PROPULSION FOR SPACE VEHICLES

O'Day, M.
May 1961
Air Force Cambridge Research Laboratories, Bedford, Mass.
AFCRL-357
AD-264,231

Electric propulsion is defined and its status reported. Descriptions involving the fundamental principles of electric propulsion are followed by appendixes which provide more detail and also contain mathematical derivations. (AI/A, 1962, #5367)

5. RAUMFAHRTANTRIEBE. STAND DER GRUNDLAGEN-FORSCHUNG UND DER ENTWICKLUNG-DEUTSCHE AUFGABENSTELLUNGEN (SPACE PROPULSION. STATUS OF BASIC RESEARCH AND DEVELOPMENT - GERMAN EVALUATION OF THE PROBLEMS)

Au, G. F.
May 1961
Deutsche Forschungsanstalt für Luftfahrt, Institut für Strahltriebwerke, Brunswick, West Germany
DFL Report 144

Very little further development is expected in the field of rocket propulsion chemicals, for, in a few years, they will be replaced by nuclear energy systems. Also, electrical propulsion systems for many flight programs will gain in importance. This report gives an overall view of the state of the art of basic research and technical advancements achieved by basic types of modern space propulsion systems. A bibliography of 712 references is included. (TPA, 1962, N62-14343)

6. NEUTRALISATION D'UN FAISCEAU D'IONS PAR INJECTION D'ELECTRONS: SOLUTIONS INDEPENDANTES DU TEMPS (NEUTRALIZATION OF AN ION BEAM BY ELECTRON INJECTION: TIME INDEPENDENT SOLUTIONS)

Dolique, J. M.
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, v. 255, no. 5, pp. 818-820, July 31, 1961

An improved model is proposed and a theoretical study discussed covering the scope of applications to missile propulsion, plasma injection in magnetic bottle, and plasma acceleration, etc. (EI, 1961) (See also Entry #261)

7. RADIAL FLUX OR FIELD OF ISOTROPIC CYLINDRICAL SOURCE OF FINITE EXTENT

Callaghan, E. E., Flax, L.
July 1961

*For additional entries see Addenda

13. INVESTIGATIONS ON THE DIRECT CONVERSION OF NUCLEAR FISSION TO ELECTRICAL ENERGY IN A PLASMA DIODE

Jamerson, F. E., Editor

January 31, 1962

General Motors Corporation, Research Laboratories,
Warren, Mich.

Annual Report, Nonr-3109(00)

Results of experimental and theoretical investigations on the use of a nuclear-generated plasma in a noble-gas plasma diode thermionic converter are presented for the period January 1, 1961 to January 31, 1962. Related programs of emitter materials development and plasma measurements are described. (AI/A, 1962, #5488)

14. ADVANCED PROPULSION CONCEPTS

Taylor, T. B.

IRE Transactions on Nuclear Science, v. NS-9, no. 1,
pp. 21-26, January 1962

The following problems are considered: (1) the scale and utilization of space exploration possible in the next 20 or 30 years as a result of advances in space transportation technology; (2) the factors involved in costs of space transportation; and (3) the specific types of propulsion systems economically feasible for use in future space projects. (AI/S, 1962, #51,226)

15. OPTIMIZATION OF INTERPLANETARY PROPULSION SYSTEMS (Presented at the International Symposium on Aerospace Nuclear Propulsion, Las Vegas, Nev., October 23-26, 1961)

Martelly, J.

IRE Transactions on Nuclear Science, v. NS-9, no. 1,
pp. 355-362, January 1962

The classical calculations for the optimization of an interplanetary propulsion system are extended to an electric multistage propulsion system. A simplification of the calculations by using nondimensional variables reduces the number of independent parameters from three to one. It is shown that the improvement of performance for multistage electrical propulsion is marked when the ratio of payload to initial vehicle weight is a few percent. This improvement practically disappears when the ratio approaches 20%, but even then the system is of value because of the increased reliability. (EEA, 1962, #11,879)

16. REVIEW OF THE CHARACTERISTICS AND DESIGN PROBLEMS OF ADVANCED PROPULSION SYSTEMS

Cruddace, R. G.

January 1962

Rocket Propulsion Establishment, Westcott, Great Britain
Technical Memorandum 247
AD-274,952

The applications, characteristics, and design problems are reviewed for the following advanced propulsion systems:

chemical, solar, nuclear-thermal, electrothermal, plasma, ion, and photon. Thirty-five references are included.

17. ELECTRIC ENGINES AT STAGE OF OPERATIONAL SYSTEM PLANNING

Judge, J. F.

Missiles and Rockets, v. 10, no. 6, pp. 22-24, February 5, 1962

Relative merits and problems of three electrical propulsion devices—the arc-jet, ion-jet, and plasma engines—are discussed. (AI/S, 1962, #51,008)

18. ENERGY CONVERSION PROGRAM. THERMIONIC CONVERTER STUDIES

Johnston, G. L.

February 14, 1962

Aerospace Corporation, El Segundo, Calif.

TDR-930(2220-50)TR-2, Semiannual Technical Report for
July 1-December 31, 1961, DCAS TDR 62-20, AF 04(647)-930
AD-274,694(Also available through U.S. Dept. of Commerce, Office of
Technical Services, Washington, D.C.)

This report contains studies on the following: plane-parallel thermionic converter; plasma spectroscopy experiment; glass enclosed converter; model of plasma converter operation; thermodynamic and transport properties of a cesium plasma; interaction of cesium vapor and refractory metal surface.

19. ELECTRICITY FOR SPACE EXPLORATION

Gradecak, V.

Ryan Reporter, v. 23, no. 1, pp. 1-3, 25, February 1962

The concept of electrochemical propulsion, enlarged by the concept of an electric air-breathing engine, is discussed. (AI/S, 1962, #51,005)

20. ION AND ELECTRIC PROPULSION SYSTEMS FOR SPACE FLIGHT: A LITERATURE SURVEY

March 1, 1962

North American Aviation, Inc., Downey, Calif.

SID 62-127

AD-282,463

(Also available through U.S. Dept. of Commerce, Office of
Technical Services, Washington, D.C.)

This report surveys the literature (335 references) on ion and electric propulsion systems from its inception through December 1961.

21. ELECTRO-PROPULSION SYSTEM APPLICATIONS

Stearns, J. W., Jr.

Astronautics, v. 7, no. 3, pp. 22-23, 74-80, March 1962

As space missions become more difficult, electrical propulsion shows a progressively greater performance advantage over other forms of propulsion. The current state of the engineering art is extrapolated to predict space probe missions to

the art of electric thrust devices is discussed, and it is concluded that, with expected advances, ion motors can meet all of the requirements of interplanetary missions, with MHD motors a promising backup. (AI/A, 1962, #60,676)

34. ELECTRICAL PROPULSION SYSTEMS FOR SPACE ROCKETS

(Translated from *Kridla Vlasti*, Prague, no. 5, pp. 14-16, 1961)
Pokorny, J.
July 12, 1962
Air Force Systems Command, Foreign Technology Division,
Wright-Patterson AFB, Ohio
FTD-TT-62-409
AD-283,901

A review is presented of three kinds of electric propulsion systems for space rockets: (1) electrothermal (arc-heated), (2) electrostatic (ionic), and (3) electrodynamic (magneto-hydrodynamic, also called plasma-type).

35. CZECHOSLOVAK IDEAS ON AEROSPACE PROPULSION

July 12, 1962
Library of Congress, Aerospace Information Division,
Washington, D. C.
AID 62-204
AD-281,817

(Also available through U. S. Dept. of Commerce, Office of Technical Services, Washington, D. C.)

Annotated drawings are presented from a popular booklet which describes Czechoslovakian aerospace propulsion ideas. The scope of the book is illustrated by the reproduced drawings. The following two ideas are of special interest: (1) Metastable atoms have a large energy excess compared to stable atoms. This excess energy might be used to drive rockets. Metastable fuels can be stored under stable conditions at extremely low temperatures. (2) Solar radiation dissociates and ionizes the individual gases that make up the high strata of the atmosphere into free radicals and ions. When these revert to the initial states, they liberate large amounts of energy. The accumulated energy of free radicals and ions might be used in aircraft propulsion at high altitudes. Such a drive might consist of a ramjet engine with an electrically charged catalyzer-screen set designed to utilize the recombination of oxygen and other types of ions, converting the energy thus liberated into thrust. Output of such an engine would depend on the composition of the upper atmosphere, the aerodynamic engine cycle, and the chemical kinetics of ion recombination.

36. SYMPOSIUM ON THERMIONIC POWER CONVERSION

Advanced Energy Conversion, v. 2, pp. 315-643,
July-September 1962

The complete papers from Sessions I, II, and III of the Symposium on Thermionic Power Conversion held in Colorado

Springs, Colorado, May 1962 are presented. The Sessions were: I-Converter Performance; II-Theoretical Models; and III-Correlation of Experiment and Theory and Oscillations. (AI/A, 1963, #71,208)

37. SPACE SHIPS-ROCKETS

(Translated from *Covjek U. Prostoru*, Naprijed, Zagreb, Yugoslavia, pp. 223-224, 1960)
Bubanj, V.
August 9, 1962
Air Force Systems Command, Foreign Technology Division,
Wright-Patterson AFB, Ohio
FTD-TT-62-1112
AD-285,833

38. EFFECT OF SCHOTTKY EMISSION ON THERMIONIC CONVERTER CURRENTS IN IGNITED MODE

Johnston, G. L.
August 15, 1962
Aerospace Corporation, El Segundo, Calif.
TDR-69(2220-50)TR-3, DCAS TDR 62-149

A theoretical model of a cesium thermionic converter, operating in the ignited mode, is investigated in order to determine the possible role of Schottky emission (produced by the accelerating field of an ion-rich emitter sheath) in causing the high currents observed in that mode. The electric field intensity adjacent to the emitter is determined as a function of plasma density, electron temperature, and emitter sheath potential by integration of Poisson's equation between sheath edge and emitter. The integration employs expressions for charged particle densities derived from the Bohm analysis of a stable positive ion sheath.

The interelectrode plasma is considered to be uniform. Simultaneous solution of relationships expressing (1) continuity of electron flow, (2) conservation of energy for electrons, and (3) balance of ion production and loss mechanisms in the plasma with the sheath field relationship, permits generation of current-voltage characteristics. It is concluded that the Schottky effect contributes substantially to the production of observed high currents. (AI/A, 1962, #61,566)

39. PROPULSION FOR INTERPLANETARY SPACE MISSIONS

Kirby, F. M.
Aerospace Engineering, v. 21, no. 8, pp. 22-30,
August 1962

A method of relating interplanetary transfer velocity requirements to a space vehicle and its propulsion system performance provides a means of analyzing major propulsion phases of interplanetary missions initiating and terminating in circular planetocentric orbits. Vehicles and propulsion systems are described and a nomograph method for analysis is given. (EI, 1962)

based on a closed cycle heat engine must reject heat into space, which can only be achieved by radiation. Fast and thermal reactors may be considered. Of the presently known energy conversion techniques, thermoelectric, thermionic, regenerative fuel cell, turbogenerators, and magnetoplasma-dynamic generator offer possibilities. These components and integrated systems are assessed and approximate performance details derived for various combinations are shown in tabular form. (*EI*, 1962)

47. PLASMA ENGINES ION AND PHOTON ROCKET ENGINES

(Translated from *Reaktivnyye Dvigateli i Bol'shiye Skorosti*, series 4, pp. 26-34, 1960)

Abians, V. Kh.

October 11, 1962

Air Force Systems Command, Foreign Technology Division,
Wright-Patterson AFB, Ohio

FTD-TT-61-464/1+2+4

AD-287,685

(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Some of the theoretical aspects of the plasma, ion, and photon engines are reviewed for space applications. The plasmatron is an apparatus for creating a plasma stream which is directed by the use of an electric arc. In the design of the plasma engine the graphite nozzle can be quickly washed away and destroyed under the action of the high temperature stream. A charged stream, on the whole, has directed motion along the nozzle, but within this stream there is chaotic motion of ions and electrons with enormous velocities. If this particle motion is regulated, then the velocity of the charged stream can be greatly increased. This principle is the basis on which the ion and photon engines are built. (*STAR*, 1963, N63-10341)

48. PROPULSION PROBLEMS IN ASTRONAUTICS

Brunthaler, W.

Electrotechnik und Maschinenbau, v. 79, no. 20, pp. 513-517,
October 15, 1962 (in German)

A calculation shows the determination of the principal quantities governing satellite orbit injection. Liquid and solid chemical propellants and their limitations are surveyed. Some characteristic data are given of German, American, and British types of rockets, and nuclear propulsion systems are discussed. While explosionlike propulsion is too violent, controlled fission reactions may be applied either for heating the propellant or for causing a series of small explosions taking place in a predetermined rhythm. By this method, discharge speeds of 12,000 to 16,000 m/sec may be obtained. A schematic sketch shows the arrangement of direct electronic propulsion which requires the use of very high currents and voltages. This kind of propulsion works very slowly and no control can be accomplished with it. It is only suitable for

overcoming "astronomical" distances. Propulsion by means of photons is briefly discussed. (*EEA*, 1963, #1612)

49. DYNAMIC ENGINES FOR SPACE POWER SYSTEMS

Kovacik, V. P.

ARS Journal, v. 32, no. 10, pp. 1511-1522, October 1962
(*AS&T*, 1963)

50. PROPULSION FOR SPACE VEHICLES: A SURVEY

Seifert, H. S. (United Technology Corp., Sunnyvale, Calif., and
Stanford University, Stanford, Calif.)

Space Science Reviews, v. 1, pp. 331-364, October 1962

A survey is presented of the various propulsion systems for space travel, emphasizing the propulsion requirements of various missions. Liquid-, solid-, and hybrid-propellant rocket engines, and nuclear, arc-jet, ion-accelerator, magnetogasdynamic, solar-sail, solar-collector, and matter-conversion propulsion methods are considered. Performance characteristics of some of the systems are included, as well as 26 references. (*IAA*, 1963, A63-11151)

51. BIBLIOGRAFIA SUI SISTEMI AVANZATI DI PROPULSIONE (BIBLIOGRAPHY ON ADVANCED SYSTEMS OF PROPULSION)

Monti, R., Napolitano, L. G. (Istituto di Aeronautica,
Università di Napoli, Naples, Italy)

Missili, v. 4, pp. 37-52, October 1962 (in Italian)

Three bibliographies are presented which contain a total of 437 references on plasma and ionic propulsion and on associated fundamental problems. A brief discussion of energy sources, conversion, and utilization precedes the bibliographies. (*IAA*, 1963, A63-13104)

52. NASA SPACECRAFT PROPULSION: WIDE-RANGING RESEARCH ATTACK LED BY LEWIS

Missiles and Rockets, v. 11, pp. 148-150, 152,
November 26, 1962

New approaches to spacecraft propulsion problems being pursued at the Lewis Research Center are discussed. These include: (1) development of permanent magnets for ion engines, (2) clustering concepts to increase thrust, (3) low-temperature MHD generators through the "Kerrebrock effect", (4) colloid and heavy-particle concepts, and (5) a new approach to space electrical power generation involving the direct conversion of nuclear energy to electricity. The last approach envisages the use of the kinetic energy of charged particles emitted from a radioisotope by natural nuclear decay to produce a high-voltage current. (*IAA*, 1963, A63-10492)

53. PROBLEMA ELEKTRICHESKIKH REAKTIVNYKH DVIGATELEI I PRYAMOGOPREOBRAZOVANIYA TEPLOVOI ENERGII V ELEKTRICHESKUYU (PROBLEMS OF REACTIVE ELECTRIC PROPULSION AND OF DIRECT CONVERSION OF THERMAL

etary flight is presented. The T-type shock-tube accelerator, the pinch accelerator, and the magnetic annular shock-tube accelerator are described briefly. (IAA, 1963, A63-13111)

**60. MECCANICA DELLA PROPULSIONE SPAZIALE
(MECHANICS OF SPACE PROPULSION)**

Crocco, L. (Scuola di Ingegneria Aero-Spaziali, Università di Roma, Rome, Italy)

In "Advances in Astronautical Propulsion," Proceedings of the Seminar held in Milan, Italy by Istituto Lombardo Accademia di Scienze e Lettere in collaboration with the Advisory Group for Aeronautical Research and Development of NATO, September 8-12, 1960, pp. 11-46 (in Italian)
Casci, C., (Politecnico di Milano, Milan, Italy), Editor
Pergamon Press, Inc., New York, N.Y., 1962

Propulsion dynamics of high- and low-thrust systems in the presence of gravity and in gravity-free space are discussed. Optimization problems and the range of possibilities available with present propulsion systems are emphasized. Interplanetary transfer orbits are calculated. (IAA, 1963, A63-13112)

**61. THE ELECTRIC ENGINE AS A PROPULSION
SYSTEM FOR THE EXPLORATION OF SPACE**

Heller, G. B. (Research Projects Div., George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)

In "Space Age Astronomy," International Astronomical Union—Douglas Aircraft Company, Inc., International Symposium, Pasadena, Calif., August 7-9, 1961, pp. 288-307
Deutsch, A. J., Klemperer, W. B., Editors
Academic Press, Inc., New York, N.Y., 1962

The state of the art in ion, arc, and magnetofluidynamic engines is surveyed, summarizing the technical difficulties in their development, flight testing techniques, and proposed missions. The three types of engine are schematically diagrammed. Fifteen references are given. (IAA, 1963, A63-14362)

62. PROPULSION DEVELOPMENTS

Hege, D. W. (Rocketdyne Div., North American Aviation, Inc., Canoga Park, Calif.)

In "Space Age Astronomy," International Astronomical Union—Douglas Aircraft Company, Inc. International Symposium, Pasadena, Calif., August 7-9, 1961, pp. 501-506
Deutsch, A. J., Klemperer, W. B., Editors
Academic Press, Inc., New York, N.Y., 1962

The characteristics of the various rocket powerplants available for space vehicles are summarized briefly. Comments on their configurations and proposed applications are included. (IAA, 1963, A63-14383)

63. INTRODUCTION TO SPACE PROPULSION PROBLEMS

(Presented at the American Society for Metals Golden Gate Conference, San Francisco, Calif., February 15-17, 1962)

Hove, J. E. (Materials Sciences Lab., Aerospace Corp., Los Angeles, Calif.)

In "Materials Science and Technology for Advanced Application," pp. 85-93

Marsh, D. R., Editor

Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962

Some of the advantages and disadvantages of chemical, direct nuclear, and electric propulsion systems are presented. Particular attention is given to the nuclear ramjet and the problem of selecting the reactor materials which, in addition to withstanding high temperatures (1200-1500°C wall temperature) and neutron bombardment, must also show high oxidation resistance. (IAA, 1963, A63-11966)

**64. A PERFORMANCE ANALYSIS OF ELECTRICAL
PROPULSION SYSTEMS**

Shelton, R. D., Johnson, W. G., Jones, B. P., King, J. C.

In "From Peenemünde to Outer Space" Commemorating the 50th Birthday of Wernher von Braun, March 23, 1962, pp. 349-376

Stuhlinger, E., Ordway, F. I., III, McCall, J. C., Bucher, G. C., Editors

National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Ala., 1962

The primary parameters which characterize the performance of electrical propulsion systems are identified, their influence on the general mission capability is evaluated, and their association with the development of particular subsystems established. Two complementary problems are associated with improving electrical propulsion performance: (1) improving the utilization efficiency of both available prime electric power and fuel, and (2) increasing the available prime power to vehicle mass. The first will be solved essentially through improvement in thrusters, and the second through improvement in prime electric power sources and spacecraft designs. Both areas are considered in detail in relation to ion thrust units and arc thrust units. (STAR, 1963, N63-15992)

**65. LA PROPULSION ÉLECTRIQUE DES VEHICLES
SPATIAUX (ELECTRICAL PROPULSION OF SPACE
VEHICLES)**

(Presented at the Deuxième Symposium Spatial Européen, Paris, France, June 18-20, 1962)

Picquendar, J. E. (Compagnie Française Thomson-Houston, Paris, France)
1962

Société Française d'Astronautique, Paris, France
Paper (in French)

A limit in the current development of high-powered chemical rockets appears to have been reached. In effect, the kinetic energy of propellants cannot exceed the total chemical energy of their constituents. To increase ejection velocity, higher energy provided by an electric generator must be used. In this way, the "electric propulsor" attains very high specific impulse values and, consequently, will allow accomplishment of distant missions with a reduced fuel consumption. The principal types of electric propulsors, their performance, and possible utilization are discussed. (TPA, 1962, N62-15028)

Ill., November 1-3, 1962)

1962

National Aeronautics and Space Administration,
Washington, D.C.

NASA SP-22

The following papers were presented:

"Introduction," by W. E. Moeckel, pp. 1-4

"Special Requirements on Power Generation Systems for
Electric Propulsion," by S. Lieblein, pp. 5-14

"Generation of Thrust—Electrothermal Thrustors," by
J. R. Jack, pp. 15-18

"Generation of Thrust—Electromagnetic Thrustors," by
G. R. Seikel, pp. 19-24

"Generation of Thrust—Electrostatic Thrustors," by
W. D. Rayle, pp. 25-30

"Advanced Concepts," by E. E. Callaghan, pp. 31-37
(STAR, 1963, N63-11512)

**70. ANALYTIC SOLUTION OF A MICROTHRUST
PROBLEM** (Presented at the ARS 17th Annual Meeting and
Space Flight Exposition, Los Angeles, Calif., November 13-18,
1962)

Shapiro, G., Paul, E. W. (Westinghouse Electric Corp.,
Baltimore, Md.)

1962

American Rocket Society, New York, N.Y.

Paper 2610-62, AF 49(638)-1002

AD-293,204

Several studies of trajectories of satellites with an additional small acceleration have been made using the standard technique of numerical integration (Cowell's method) on high speed computers. Examples of the inaccuracy of this method are given. A mathematical model applicable to the perturbation of an *Orbiting Solar Observatory* by radiation pressure or to testing an electrical propulsion system is used to illustrate one analytical procedure, the Krylov-Bogoliuboff method, which results in a closed form solution to first order. In the two-dimensional case, the major axis remains constant while the orbit approaches a straight line so that eccentricity tends to one. The major axis again remains unchanged in the three-dimensional case, but the eccentricity, inclination, and argument of perigee oscillate between limits which are independent of the magnitude of the acceleration due to the radiation pressure.

**71. DEVELOPMENT OF ELECTRIC PROPULSION
POWER SYSTEMS** (Presented at the ARS 17th Annual
Meeting and Space Flight Exposition, Los Angeles, Calif.,
November 13-18, 1962)

Elliot, D. G. (Jet Propulsion Laboratory, California
Institute of Technology, Pasadena)

1962

American Rocket Society, New York, N.Y.

Paper 2652-62

The present status of space powerplant development for electric propulsion can be summarized as follows: (1) auxil-

iary powerplants of increasing power level and decreasing specific weight will become available over the next few years to permit attitude and trajectory control with small electric thrusters; (2) the decision having been made to develop large space powerplants for prime propulsion, development at the 300- to 1000-kw level is proceeding; and (3) three types of conversion systems—turboelectric, thermionic, and liquid MHD—appear to be developable to long-life, lightweight space powerplants, and are currently receiving the major effort. Specific weights and power levels of some present and future space power systems are compared. Propulsion power supplies are discussed in relation to requirements of specific weight and size. Basic powerplant problems, such as power conditioning, radiators, and materials, are considered. Conversion cycles covered in some detail and compared are (1) turboelectric; (2) thermoelectric, thermionic, ion and colloid; and (3) MHD. (AI/A, 1963, #70,676)

**72. THE EFFECT OF VELOCITY DISTRIBUTIONS ON
POWER-LIMITED PROPULSION SYSTEM** (Presented at
the ARS Electric Propulsion Conference, Berkeley, Calif.,
March 14-16, 1962)

Shelton, R. D., Lacy, L., Potter, R. A., Stuhlinger, E.
1962

American Rocket Society, New York, N.Y.

Paper 2436-62

The effect of a distribution in the velocity of propellant ejection upon propulsive efficiency of a space vehicle is analyzed. It is assumed that the vehicle accelerates rectilinearly from rest in field-free space, and that the characteristics of the propulsion system do not change during the acceleration time. The beam efficiency factor, defined as the ratio of the square of the average velocity to the average of the square of the velocity, is shown to be as important in determining mission capability as such factors as specific power and propulsion time. The fallacy of evaluating propulsion systems in terms of the thrust-to-power ratio is demonstrated for situations involving neutral efflux, and an alternative method based on the ratio of actual thrust to theoretical thrust is suggested. (IAA, 1962, #62-8209)

**73. RAUMFAHRT—GESTERN, HEUTE UND MORGEN
(SPACE FLIGHT—YESTERDAY, TODAY, AND
TOMORROW)**

Sänger, E. (Forschungsinstitut für Physik der
Strahlantriebe e.V., Stuttgart-Vaihingen, West Germany)
Astronautica Acta, v. 8, no. 6, pp. 323-342, 1962 (in German)

The development of rocket engines and space vehicles is surveyed historically. It is indicated that the development of rocket engines with exhaust velocities up to 5000 m/sec will permit the use of one- or two-stage vehicles for launching satellites into Earth orbit, and will limit the present ballistic space-flight techniques to aeronautical flights between the Earth surface and Earth orbits. It is seen that the reduction in the number of rocket stages, together with the develop-

thrust-to-weight ratios, optimum thrust programs for escape tend toward the optimum curve for specified final velocity and arbitrary range. Regardless of the initial thrust-to-weight ratio, the departure of the optimum Earth-escape thrust program from that of constant thrust per unit mass is considerable. (IAA, 1963, A63-11947)

79. STATIC NUCLEAR THERMOELECTRIC SYSTEM FOR SPACE

Kueser, P. E., Merrill, P. S., Tauch, F. G.
IEEE Transactions on Applications and Industry,
no. 64, pp. 402-405, January 1963

A prototype thermoelectric generator is described which produced 250 w of electric power at space operating temperatures. Waste-heat radiators for the system, having constant and tapering fin thicknesses, are discussed. Curves are presented of performance versus fin number and length for both tapered and constant-thickness fins. Weight and electric power capability of a present state-of-the-art thermoelectric generator-radiator system is presented in curve form and shows a 245-lb weight for a 250-w system, exclusive of the reactor and shielding. (AI/A, 1963, #71,603)

80. MISSION ANALYSIS FOR SPACE VEHICLES POWERED BY LOW-ACCELERATION, POWER-LIMITED PROPULSION DEVICES

Donham, J. J., Golden, C. J.
January 1963
Lockheed Aircraft Corporation, Sunnyvale, Calif.
Final Report, ASD TDR-62-1060, AF 33(657)-8232
AD-297,313

A computer program intended to provide a means for the planning of space missions for vehicles powered by low-acceleration, power-limited propulsion systems is described in detail. Optimum interorbit transfer missions are discussed for realistic design conditions when utilizing the 30- and 60-kw SNAP unit as the electrical power supply. The required mass expenditures and travel times as a function of the vehicle's initial weight on-orbit, available electrical power, engine performance parameters, and initial orbit are presented. An optimum program for the execution of the required orbit plane change to establish the 24-hr equatorial orbit is proposed. The application of electrical propulsion for a round-trip Earth-Moon logistic transportation system is demonstrated considering a 300-kw SNAP unit as the electrical power source. The mission starts from an Earth-centered 500-mi circular orbit, transfers to a Moon-centered 100-mi circular orbit, deposits the transported cargo and returns to the original 500 mi Earth-centered orbit. Optimization of the thrust direction as well as the magnitude to minimize the mass expenditure during the entire transfer is demonstrated.

81. EIN KERNREAKTOR FÜR DEN ENERGIEBEDARF ELEKTRISCHER ANTRIEBE (A NUCLEAR REACTOR

TO MEET THE POWER REQUIREMENTS OF ELECTRIC PROPULSION SYSTEMS)

Höcker, K. H., Unger, H., Kürz, G., Pruschek, R. (Technische Hochschule Stuttgart, Institut für Hochtemperaturforschung, Stuttgart, West Germany)
Raketentechnik und Raumfahrtforschung, v. 7, no. 1, pp. 1-5, January-March 1963 (in German)

A brief description of the neutron physics and heat-transfer principles is given in view of the development of a nuclear reactor for generating electric energy in space environments. A practical example is discussed. It is shown that the conversion of heat to electricity is performed by thermionic energy transducers rather than by the application of the Rankine or Brayton cycle. (IAA, 1963, A63-12807)

82. A COMPARISON OF THE CAPABILITIES OF ELECTRICAL PROPULSION SYSTEMS FOR CO-PLANAR ORBITAL TRANSFER MISSIONS

(Presented at the 14th Annual Meeting of the Deutsche Gesellschaft für Raketentechnik und Raumfahrt e.V., Space Flight Propulsion and Applications Symposium, Brunswick, West Germany, June 21-23, 1962)
Stewart, P. A. E. (Bristol Siddeley Engines, Ltd., Filton, Bristol, Great Britain)
Raketentechnik und Raumfahrtforschung, v. 7, no. 1, pp. 5-14, January-March 1963

Extrapolated data for the European space program are assessed, showing electric propulsion requirements and heavy launcher capability. Thrust-vector programs suitable for electrically propelled stages are considered, and the contrast thrust case is chosen for the initial analysis. Parameters for optimization are examined, and the interrelationship of propulsion time, specific impulse, mass ratio, and the parameter α/η (kg/jet kw) is shown. Attention is then focused on power supplies, and a nuclear turboelectric powerplant suitable for this application is described. Electric thrusters are examined on the basis of efficiency over a range of specific impulse values. Dependencies in the electric stage design are outlined, and three typical stages—propelled by electrothermal, electromagnetic, and electrostatic propulsion systems—are compared. Stage-weight breakdowns are given and payloads are extracted. Also included are 147 references. (IAA, 1963, A63-12808)

83. ELEKTRISCHE ANTRIEBS- UND STEUERUNGSSYSTEME FÜR 24-STUNDEN-SATELLITEN (ELECTRIC PROPULSION AND CONTROL SYSTEMS FOR 24-HR SATELLITES)

Au, G. F. (Deutsche Forschungsanstalt für Luft- und Raumfahrt e. V., Institut für Strahlantriebe, Brunswick, West Germany)
Raketentechnik und Raumfahrtforschung, v. 7, no. 1, pp. 15-27, January-March 1963 (in German)

The problems related to orbit transfer of satellites from a 200-km circular orbit to the 24-hr equatorial orbit are studied under optimal conditions. For this mission, only such electric

spacecraft relates the mission to the propellant requirements. The proposed *Apollo* propulsion system for landing three men on the Moon is briefly described, and the service and lunar landing modules are considered. The nuclear rocket is seen to have the potential of doubling the propellant performance when compared with the liquid hydrogen-oxygen chemical combustion rocket. The principles of the nuclear rocket are sketched, its advantages and disadvantages noted, and the program for developing nuclear rocket technology is summarized. Electric rockets are shown to include such varying types as arc jets, electromagnetic propulsion systems, and electrostatic propulsion units; basic properties of the electric rockets are briefly considered. (IAA, 1963, A63-13379)

90. FEASIBLE DIRECT HEAT TO POWER, STEP SOUGHT BY ENGINEERS

Steel, v. 152, p. 67, April 8, 1963
(AS&T, 1963)

91. REDUCTION OF FROZEN FLOW LOSSES BY NONEQUILIBRIUM HEATING

Chen, M. M.
AIAA Journal, v. 1, no. 5, pp. 1204-1206, May 1963
(AS&T, 1963)

92. SPACE POWERPLANT NEEDS AND SELECTION

Bernatowicz, D. T., Guentert, D. C., Klann, J. L.
Astronautics and Aerospace Engineering, v. 1, no. 4, pp. 22-26, May 1963

Criteria for selecting and evaluating power systems for future space missions are (1) mass, (2) ease of integration into total vehicle system, (3) compatibility with space environment, (4) lifetime and reliability, (5) hazards to crew, (6) cost, and (7) availability or status of technology. The influence of these criteria on mission planning and success is described. (AI/A, 1963, #80,635)

93. ANALYTICAL STUDY OF TURBINE-GEOMETRY CHARACTERISTICS FOR ALKALI-METAL TURBO-ELECTRIC SPACE POWER SYSTEMS

Glassman, A. J., Futral, S. M.
May 1963
National Aeronautics and Space Administration,
Washington, D.C.
NASA TN D-1710

This study was made to determine the effects of turbine-inlet temperature and working fluid on the number of turbine stages, turbine diameter, and rotative speed required for a system producing 1 Mw of electric power. Sodium, potassium, rubidium, and cesium were investigated as possible working fluids, with turbine inlet temperatures ranging from 2000 to 2600°R. In addition, the effects of varying the strength of the rotor structural material and of mean-section blade-diameter configuration were considered. (AI/A, 1963, #80,089)

94. MARS—A TARGET FOR ADVANCED PROPULSION
(Presented at the American Astronautical Society Symposium on the Exploration of Mars, Denver, Colo., June 6-7, 1963)
Finger, H. B.

June 6, 1963

National Aeronautics and Space Administration, Office of Scientific and Technical Information, Washington, D.C.
News Release

Although the mission to Mars will not be undertaken until the *Apollo* project begins to phase out, the importance of preparing the basic information and technology is stressed for two reasons: (1) to avoid wasteful crash programs, and (2) by directing long-range interest toward Mars landing missions, the capability is provided for other missions of interest, such as orbital space stations, which are logical stepping stones to planetary missions. Since nuclear rockets will undoubtedly be used for at least the upper stages of the Mars mission, the present status of nuclear propulsion technology is discussed. The conclusion is reached that no major technological breakthrough will be required to develop a nuclear rocket patterned after the Kiwi reactor now being tested. Electrical propulsion systems, although offering great potential on paper, have the engineering drawback of not being suitable for a ground development and test program. A careful, realistic determination of the areas which offer the greatest promise must be made in order to gain real accomplishments in space. (STAR, 1963, N63-16834)

95. DEVELOPING ELECTRIC-PROPULSION POWERPLANTS

Elliott, D. G. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena)
Astronautics and Aerospace Engineering, v. 1, no. 5, pp. 82-93, June 1963

Recent developments in turboelectric, thermionic, and MHD electric propulsion systems are surveyed. The specific weights and power levels of some present and future auxiliary space power sources are compared. Particularly mentioned is the development of the 3-kw SNAP 2 system and the 30-kw SNAP 8 system, the advent of which will permit orbital corrections, spiral-orbit surveys, station-keeping, and other applications requiring precise control and high total impulse. Research on powerplants for prime propulsion in the 300-kw range to provide accelerations on the order of $5 \times 10^{-5} g$ is noted. Data are presented which indicate that materials and techniques are becoming available for large space powerplants weighing as little as 20 lb/kw or less. Twenty-three references are included. (IAA, 1963, A63-17564)

96. ELECTRIC PROPULSION, A CUSTOM ABSTRACT SEARCH

Chapman, G. E., Jr.
June 1963

to achieve realistic starting weights, and allowances are made for propellant boiloff losses for nuclear and chemical systems, and for reactor aftercooling for nuclear units. It is shown that: (1) nuclear heat transfer propulsion systems have no payload capability for the *Atlas-Centaur* booster, which will therefore be limited to chemical upper stages; (2) the nuclear rocket exhibits a lower payload capability than the chemical systems with the *Saturn C-1B*; (3) with *Saturn C-5*, the nuclear system offers a 30% increase in payload compared to chemical systems for a probe mission; and (4) the general relationships between nuclear and chemical propulsion systems with the *Nova* vehicle are similar to those with the *Saturn C-5*. Seventeen references are included. (IAA, 1963, A63-20532)

102. SPACECRAFT ELECTRIC GENERATING AND PROPULSION SYSTEM INTEGRATION STUDY. PART I—SYSTEM INTEGRATION STUDIES

Brown, H., Editor

August 1963

General Electric Company, Cincinnati, Ohio

Final Report for April 1, 1962–March 31, 1963,

ASD TDR-63-428, Pt. I, AF 33(657)-8488

This program consisted of the adaption of the LEADER technique to the analysis of nuclear-electric power and propulsion systems integration. Analytical models of each of the major components of a 350-kw SPUR arc-jet system and a 1-Mw SPUR ion-engine system were developed and processed by the LEADER optimization technique in order to demonstrate its capabilities for obtaining the design criteria for minimizing overall system weight. The specific output of the program included the optimum design variables, the constraints preventing further design improvement, and the sensitivity of the final design to subsequent changes in the independent design variables. (STAR, 1963, N63-22446) (See also Entries #43, 57, 443)

103. SPACECRAFT ELECTRIC GENERATING AND PROPULSION SYSTEM INTEGRATION STUDY. PART II—LEADER USER'S MANUAL

Brown, H., Editor

August 1963

General Electric Company, Cincinnati, Ohio

Final Report for April 1, 1962–March 31, 1963,

ASD TDR-63-428, Pt. II, AF 33(657)-8488

This report contains a description of the analytical techniques and computer programming effort required to develop an analytical model of a spacecraft electric generating and propulsion system, and incorporate the model into the LEADER system optimization program. (STAR, 1963, N63-22445)

104. ELECTRIC PROPULSION DEVELOPMENT. PROGRESS IN ASTRONAUTICS AND AERONAUTICS. VOLUME 9

Stuhlinger, E., Editor (George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)

Academic Press, Inc., New York, N.Y., 1963

Technical papers are presented which are based mainly on the American Rocket Society Electric Propulsion Conference held at Berkeley, Calif., March 14–16, 1962. (See Entries #105, 106, 223, 224, 225, 226, 227, 228, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 475, 476, 477, 478, 479, 480, 522, 523)

105. PLASMA THERMODYNAMICS. II. COMPLEX EQUILIBRIA IN NONIDEAL SYSTEMS (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14–16, 1962)

McGee, H. A., Jr. (George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala., and Dept. of Chemical Engineering, Georgia Institute of Technology, Atlanta), Heller, G. B. (George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 443–459

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

A procedure is developed for the computation of the thermodynamic properties of plasmas when considering the gas to be a complex, nonideal mixture, using a minimization of free-energy technique. The population of excited levels, as well as the thermal properties the equilibrium compositions over a rather coarse network of temperatures and pressures, is presented for the hydrogen plasma. The violation of certain requirements for thermodynamic consistency that results from the unrelated choice of (1) an ionization energy decrement function, and (2) a real gas equation of state, is discussed. When working with the lithium plasma, these considerations are shown to lead to a very large dependence on the path for thermodynamic calculations of the ordinary sort which involve differences in one of the energy functions. This effect is significant only because of the inordinately low ionization potential of this substance. (IAA, 1963, A63-25948)

106. POTENTIALITIES OF AIR-SCOOPING ELECTRICAL SPACE PROPULSION SYSTEMS (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14–16, 1962)

Reichel, R. H., Smith, T. L., Hanford, D. R. (The Boeing Co., Seattle, Wash.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 711–743

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

A discussion is presented of mission and system interactions and optimizations when using planetary atmospheres as a propellant source for electrostatic or electromagnetic propulsion systems. The concept consists of injecting the space vehicle minus propellants into a low-altitude orbit, simultaneously scooping and liquefying air as well as overcoming drag, and then executing the space mission with the same

Conference, Colorado Springs, Colo., March 11-13, 1963)
Toms, R. S. H., Eilenberg, S. L. (Electro-Optical Systems,
Inc., Pasadena, Calif.)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-008B

A method is presented for correlating the results of many mission studies by plotting payload against a mission-difficulty parameter which is defined as the velocity increment from an Earth orbit that would be required for a minimum-energy impulsive transfer. The locations of some of the boundaries are discussed, and propulsion system selection maps are presented for low-time/cost missions and for low-cost slow missions. The published results of several authors are extrapolated and plotted on the maps, showing fair agreement. The study attempts to be objective with respect to the favorable aspect of chemical and nuclear thermal propulsion. The superiority of electric propulsion appears to be obvious for all manned missions beyond the Moon and for a large class of unmanned missions to the planets. From the study it is concluded that even with relatively heavy power supplies, the electric rocket has a much higher potentiality than is generally believed. Eighteen references are included. (IAA, 1963, A63-15502)

112. ELECTRIC PROPULSION FOR CONTROL OF STATIONARY SATELLITES.
APPENDIX A: EQUIPMENT CHARACTERISTICS.
APPENDIX B: STATIONKEEPING AND ATTITUDE CONTROL OF SPIN-STABILIZED VEHICLE.
APPENDIX C: STATIONKEEPING AND ATTITUDE CONTROL OF INERTIALLY ORIENTED VEHICLE.
APPENDIX D: PERTURBING EFFECTS OF SOLAR AND LUNAR GRAVITATIONAL ATTRACTION ON INCLINATION OF SATELLITE ORBITS.

(Presented at the AIAA Electric Propulsion Conference,
Colorado Springs, Colo., March 11-13, 1963)

Boucher, R. (Hughes Aircraft Co., Culver City, Calif.)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-009

AD-406,682

The application of electric propulsion engines to attitude control and the station keeping of 24-hr stationary satellites is analyzed. The performance of the electric propulsion system is compared with that of contemporary cold gas, monopropellant, and bipropellant propulsion systems. Both a 500-lb spin-stabilized and a 1500-lb three-axis-controlled satellite (compatible with current NASA boost vehicles) are examined, and each type of propulsion system is compared as a function of mission duration and maneuver requirements. (IAA, 1963, A63-15496)

113. PROBLEMS OF MILLIPOUND THRUST MEASUREMENT—THE "HANSEN SUSPENSION" (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

Carta, D. G. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-034

The best measurements, to date, of millipounds of thrust have been made by the "Hansen Suspension" system considered in this paper. Measurements of thrust in the millipound region with a sigma of 1% were found repeatable and practical. Problems which led to the need and use of the "Hansen Suspension" are considered in detail. Also discussed are problems which are likely to be encountered in any low-level thrust measuring system. The methods of calibration and the accuracies involved are given careful attention. With all parameters optimized and calibration techniques perfected, the system was found capable of a resolution of 10 μ lb. Thrust measurements made by the "Hansen Suspension" were compared with measurements of a less sophisticated device. (IAA, 1963, A63-16691)

114. COMPARISON OF ATTITUDE CONTROL TORQUERS FOR TRANSORBITAL MISSIONS (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

Ryan, R. L., Clark, R. A., Jr. (Systems Dept., Westinghouse Astronuclear Laboratory, Pittsburgh, Pa.)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-037

The available attitude-control torquing systems are compared on the basis of weight and reliability considerations. To illustrate a general approach to the problem, the attitude-control torquer system weight for a variety of space missions is considered. Vehicle disturbances are discussed and their magnitudes and resultant momentum requirements are compared. For example, the estimated magnitude of the disturbances encountered during the geocentric and heliocentric portion of interplanetary missions—gravitational effects, magnetic fields, and solar pressure—is based on a survey of what is considered to be the best available data. Calculations for mission duration are based on the Irving-Blum method. It is concluded that the most desirable system for an interplanetary mission of up to two years' duration is a combination of electric engines backed up with a cold gas system. (IAA, 1963, A63-15458)

115. ELECTRIC PROPULSION REQUIREMENTS FOR PLANETARY AND INTERPLANETARY SPACECRAFT (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

119. ELECTRICAL PROPULSION TESTING RESEARCH AT THE ARNOLD ENGINEERING DEVELOPMENT CENTER (Presented at the AIAA Summer Meeting, Los Angeles, Calif., June 17-20, 1963)

Lennert, A. E. (ARO, Inc., Tullahoma, Tenn.)
1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-240, AF 40(600)-1000

A research program to obtain design criteria for electric propulsion test facilities, and to devise methods for long-term testing of complete electric propulsion systems is described. Considered are: (1) test requirements for electric propulsion systems; (2) basic test facility problems, including the test chamber design and a collector system design; (3) an analysis of collector system research sputtering phenomena; (4) collector system research; and (5) the electric propulsion pilot test facility. Results of sputtering research are presented which indicate that present collector systems are unsuitable for extended lifetime tests. A facility capable of simulating launch trajectories and providing transient data is described. Thirteen references are given. (IAA, 1963, A63-18845)

120. PERFORMANCE OF CESIUM THERMIONIC DIODES OPERATED IN SERIES-PARALLEL CIRCUITS

(Presented at the American Rocket Society Space Power Systems Conference, Santa Monica, Calif., September 25-28, 1962)

Holland, J. W. (Atoms International Div., North American Aviation, Inc., Canoga Park, Calif.)

In "Power Systems for Space Flight. Progress in Aeronautics and Astronautics. Volume 11," pp. 823-844

Zipkin, M., Edwards, R. N., Editors

Academic Press, Inc., New York, N.Y., 1963

An experimental investigation has been conducted of the electric power degradation from the operation of many series-parallel circuited cesium diodes in a thermionic reactor when a nonflattened nuclear power distribution exists over the volume of the reactor core. In this experiment, the loss of power and efficiency due to unequal heat inputs to series- or parallel-connected diodes is measured, and the operating characteristics of a multiple-diode system are studied. The results are applied to a specific thermionic reactor configuration with a ratio of maximum to minimum diode heat input of 1.85. The minimum degradation of power and efficiency was found to be 41% and 19%, respectively, at optimized operating conditions. (IAA, 1963, A63-25004)

121. SURVEY OF ELECTRICALLY POWERED ROCKETS

(Presented at the 14th International Astronautical Congress, Paris, France, September 25-October 1, 1963)

Seifert, H. S. (United Technology Corp., Sunnyvale, Calif., and Stanford University, Stanford, Calif.)

1963

International Astronautical Federation, Paris, France

IAF Paper 110

The relative status of chemical and electric propulsion is discussed briefly, followed by a review of nuclear-electric rockets. Detailed coverage is given to electrostatic, electrothermal, and electromagnetic propulsors. Also included are 98 references. (IAA, 1963, A63-25673)

122. ELECTRIC PROPULSION FOR MANNED MISSIONS

Denington, R. J., LeGray, W. J., Shattuck, R. D. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

In "Engineering Problems of Manned Interplanetary Exploration," Proceedings of the AIAA and NASA Conference on the Engineering Problems of Manned Interplanetary Exploration, Palo Alto, Calif., September 30-October 1, 1963, pp. 145-159

American Institute of Aeronautics and Astronautics, Inc., New York, N.Y., 1963

The possibilities of using electric propulsion for space missions are discussed. This type of system appears to be competitive with chemical and nuclear systems if lightweight, long-lived engines can be developed. Electric thrusters are considered, as are Rankine-cycle and thermionic powerplants. (IAA, 1963, A63-24242)

123. OPTIMISATION DE LA PROPULSION TRANS-SATELLITE NOTAMMENT AVEC ALLEGEMENT PROGRESSIF DU GENERATEUR D'ENERGIE (OPTIMIZATION OF TRANS-SATELLITE PROPULSION PARTICULARLY BY THE PROGRESSIVE REDUCTION IN WEIGHT OF THE POWER GENERATOR)

Martelly, J. (Conservatoire National des Arts et Métiers, Paris, France)

In "XIIth International Astronautical Congress Proceedings," Washington, D.C., October 1-7, 1961, Volume I, pp. 96-120 (in French)

Baker, R. M. L., Jr., Makemson, M. W., Editors

Academic Press, Inc., New York, N.Y., 1963

The conventional optimization calculations concerning electrical propulsion with variable exhaust velocity are extended to the case in which the electrical generator mass can be reduced during flight. For this, the generator is made up of parallel working units, which can be jettisoned separately. This procedure is justified also by reliability considerations. The mathematical solution is derived in terms of simple functions describing the optimum motion—i.e., programming of the masses and exhaust velocity as a function of time. It is shown that the reduction in generator mass is advantageous if the payload is less than one quarter of the initial mass. The use of reduced values is proposed in order to simplify the optimization calculations and their discussion. In this way the solutions are expressed with a single independent parameter instead of three. (IAA, 1963, A63-21245)

ELECTROMAGNETIC*

127. PERFORMANCE OF A HYDROMAGNETIC PLASMA GUN

Marshall, J., Jr. (Los Alamos Scientific Lab., University of California, Los Alamos, N. Mex.)
Physics of Fluids, v. 3, no. 1, pp. 134-135, January-February 1960

A capacitor discharge was used for the driving force in this study. Strong shock was observed from the first pulse with a velocity of 10^6 cm/sec, followed by three or four discharges which produced plasmoids moving at about 5×10^6 cm/sec. Efficiency of the accelerator was estimated to be about 3% in the production of high-velocity plasmoids. Suggestions are made for future improvement. (EI, 1961)

128. BIBLIOGRAPHY ON MAGNETOHYDRODYNAMICS, INCLUDING PLASMAS

September 1960
Ministry of Aviation, Technical Information and Library Services, Great Britain
TIL/BIB/45
(AI/A, 1962, #5503)

132. MAGNETOHYDRODYNAMIC POWER GENERATOR FEASIBILITY STUDY

February 1961
Armed Services Technical Information Agency, Arlington, Va. AD-257,619
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

129. PLASMA ACCELERATORS

Slawsky, M. M. (Air Force Office of Scientific Research, Washington, D.C.)
In "1960 Transactions of the IRE Fifth National Symposium on Space Electronics and Telemetry," Washington, D.C., September 19-21, 1960
Institute of Radio Engineers, Inc., New York, N.Y., 1960, Paper 3-3

The research effort in plasma acceleration for propulsion is viewed with respect to the fundamentals of the propulsion problems. Since plasma accelerators can be thought of as electric motors the various acceleration concepts are presented as shunt, series or induction devices. Thirteen references are included. (EI, 1961)

The study made by Pratt & Whitney Aircraft is described. Generator requirements included output of 1000 Mw at 15,000 v, starting within 10 sec, operating continuously for periods between 10 sec and $\frac{1}{2}$ hr, and having a total life of about 20 hr. The procedure used to establish optimized design is described. The plasma is created by seeding combustion products of hydrocarbon fuel and oxygen with potassium nitrite; the magnetic field is produced by a copper-coil electromagnet which is cooled by liquid oxygen to reduce electrical heating losses. (EI, 1962)

130. MAGNETOHYDRODYNAMICALLY DRIVEN VORTICES

Lewellen, W. S.
Proceedings of the Heat Transfer and Fluid Mechanics Institute, pp. 1-15, 1960

An MHD body force is considered as a means of driving a two-dimensional, axisymmetric, steady vortex in a viscous, conducting fluid. Analytical solutions are found for a case involving axial currents. Results are plotted for reasonable values of the parameters involved and the effect of applied magnetic and electric fields on temperature and pressure distributions in an adiabatic, compressible vortex is presented. The study's pertinence to propulsion research is established. (EI, 1961)

133. AN EXPERIMENTAL STUDY OF CONTINUOUS PLASMA FLOWS DRIVEN BY A CONFINED ARC IN A TRANSVERSE MAGNETIC FIELD

Barger, R. L., Brooks, J. D., Beasley, W. D.
March 1961
National Aeronautics and Space Administration, Washington, D.C.
NASA TN D-716

A crossed field, plasma accelerator was operated by Langley Research Center. The highest maximum measured velocity of the flow, which was driven by the interaction of electric and magnetic fields, was 500 m/sec. Some of the problems discussed are ion slip, stability and uniformity of discharge, effect of magnetic field on electron emission, use of pre-ionization, and electrode contamination. The applicability of these flows to aerodynamic and re-entry testing, space propulsion, and materials research is examined. (EI, 1961)

131. EXPERIMENTAL STUDY OF SINGLE-COIL INDUCED-ELECTROMOTIVE-FORCE PLASMA ACCELERATOR

Matthews, C. W., Cuddihy, W. F.
January 1961
National Aeronautics and Space Administration, Washington, D.C.
NASA TN D-639

134. A STUDY OF LAMINAR COMPRESSIBLE VISCOUS PIPE FLOW ACCELERATED BY AN AXIAL BODY FORCE, WITH APPLICATION TO MAGNETO-GASDYNAMICS

Martin, E. D.
April 1961
National Aeronautics and Space Administration, Washington, D.C.
NASA TN D-855

*For additional entries see Addenda

140. THEORETICAL STUDY OF THE ELECTROHYDRO-DYNAMIC GENERATOR

Smith, J. M.

November 27, 1961

General Electric Company, Space Sciences Laboratory,
Philadelphia, Pa.

R61SD192

An electrical power generator is studied which is based upon the principle of the Van de Graff generator, but differs from it primarily in that the charge is transported in a moving gas rather than on a moving belt. The electrical and thermal properties of such a generator are analyzed using the solution of the one-dimensional, inviscid, constant flow equations for an ionized gas coupled with Maxwell's equations. (AI/A, 1962, #5487)

141. PLASMA PHYSICS—ELEMENTARY REVIEW

Bachynski, M. P.

Proceedings of the IRE, v. 49, no. 12, pp. 1751-1766,
December 1961

Plasmas as they exist in nature are described and the role of plasma physics in attempts at ignition, control, and diagnosis of thermonuclear fusion reactions is discussed. The effect of plasmas on communication and telemetry from space and re-entry vehicles is examined. Propulsion techniques which utilize plasmas are reviewed and the possibilities of incorporating plasmas in practical devices explored. A total of 133 references is included. (EI, 1962)

142. MHD APPLICATIONS FOR SPACE AND GROUND POWER (Presented at the First International Congress and Exposition of Automotive Engineering, Detroit, Mich., January 9-13, 1961)

McIlroy, W., Kunen, A. E.

1961

Society of Automotive Engineers, Inc., New York, N.Y.
Paper 312B

Propulsion devices, as well as the plasma pinch engine under development by Republic Aviation Corporation are reported. Problems bearing on the operation of MHD pulsed plasma accelerators and specific impulse, and energy conversion efficiency in the selection of a working engine are discussed. The application of magnetohydrodynamics to electrical generation for ground and space installations and materials problems is reviewed as well as the application of a magnetic field to a high power thermionic converter to increase efficiency. (EI, 1961)

143. EXPERIMENTAL STUDIES OF PULSED PLASMA PINCH SPACE ENGINE (Presented at the SAE National Aeronautic Meeting and Display, New York, N.Y., April 4-7, 1961)

Cavalconte, C. C., Granet, I., Guman, W. J.

1961

Society of Automotive Engineers, Inc., New York, N.Y.
Paper 346D

Work at Republic Aviation aimed at providing thrust for satellites in orbital flight and at developing a pulsed plasma pinch engine is reported. Thrust is variable depending on pulse rate, propellant mass, and energy per pulse. The pinch effect principle is employed and thrust is estimated by calculation. Optimization of performance to arrive at best electrode shape and charge capacitors efficiently is described as well as the prototype engine XE-1, having 1-kw maximum rating and output of 0.01 lb thrust at 2 pps repetition rate.

144. INSTRUMENTATION FOR PULSED PLASMA ENGINE
Aronowitz, L., Steinberg, A.

In "Proceedings of the National Aerospace Electronics Conference, Dayton, Ohio, May 8-10, 1961," pp. 275-282
Institute of Radio Engineers, Inc., New York, N.Y., 1961
(Available through NAECON, Dayton, Ohio)

The measurement techniques used in Republic Aviation's Plasma Propulsion Laboratory in the development of the pulsed plasma engine are reviewed. The engine is operated in a vacuum chamber, and control and diagnostic information must be sent to and from it. (EI, 1962)

145. PULSED PLASMA ACCELERATOR FOR SPACE PROPULSION (Presented at the SAE National Aeronautic Meeting, Los Angeles, Calif., October 9-13, 1961)

Maes, M. E.

1961

Society of Automotive Engineers, Inc., New York, N.Y.
Paper 419C

A comparison of chemical and electrical propulsion systems for interplanetary missions and for satellite orientation showed the advantages of the latter. The system consisted of an accelerator (which produced the thrust), a propellant storage tank, and a nuclear reactor electric generator (which supplied the energy). Electrical energy conversion methods are discussed. The Boeing Company's work on a confined parallel rail pulsed plasma accelerator, the main objective of which was examination of its efficiency, thrust level, and operating lifetime, is considered. (EI, 1961)

146. PLASMAPHYSIK IN DER HYPERSCHALL-AERODYNAMIK UND IN DER TRIEBWERKSTECHNIK (PLASMA PHYSICS IN HYPERSONIC AERODYNAMICS AND IN POWERPLANT ENGINEERING) (Presented at the WGL Tagung, Freiburg im Breisgau, Germany, October 10-13, 1961)

Peters, Th. (Forschungsinstitut für Physik der Strahlantriebe, Stuttgart-Vaihingen, Germany)

In "Wissenschaftliche Gesellschaft für Luftfahrt e.V., Jahrbuch"

Blenk, H., Editor

Verlag Friedrich Vieweg & Sohn, Brunswick, West Germany,
1961 (in German)

The derivation of equations of magnetohydrodynamics, by means of which it is possible to explain the conditions under which typical MHD effects are to be expected, is presented.

The acceleration of a plasma by a capacitor discharge between coaxial electrodes is studied for (1) a shock tube having an initially uniform gas distribution, and (2) a plasma gun which accelerates a constant mass into a vacuum. Differential equations written for the first case for a simple snowplow model and solved by analog computer are found to closely predict peak plasma velocities for a certain range of pressures. Experimental study shows that the actual current distribution is rather complex. Computer solutions are also obtained for the plasma gun which seems to be intrinsically capable of greater efficiency than the shock tube. (AI/S, 1962, #51,395)

153. MAGNETOGASDYNAMIC THRUST VECTORING OF ROCKET MOTORS, INCLUDING THE EFFECTS OF FINITE ELECTRON-ION RECOMBINATION KINETICS. A PARAMETRIC STUDY

Rosner, D. E.

February 1962

AeroChem Research Laboratories, Inc., Princeton, N.J.

TN-41, NOw-60-0536-c

Universal curves are presented to facilitate the prediction of MHD control forces in rocket motor practice. A set of equilibrium calculations also required for this purpose is included for 21 rocket propellant combinations with alkali atom seeding. Since the nozzle expansion process can lead to electrical conductivities at the exit section much larger than those corresponding to local ionization equilibrium, a graphical method is introduced and discussed which enables quantitative estimates to be made of the extent of this nonequilibrium enhancement as well as the conditions under which it can be ignored. By combining this material, it is possible to extract general information as to the independent factors favoring maximum exhaust jet interaction with the applied magnetic field. Some of the major factors (other than large field strength) giving rise to favorable conditions are (1) presence of low ionization potential materials in "hot" chambers, (2) small values of the effective specific heat ratio, (3) moderate rather than extremely large chamber pressures, and (4) large physical size. It appears, from the calculations carried out thus far, that control forces of the order of 0.1 to 1.0% of the gross thrust are attainable by applying large magnetic fields (10,000 to 30,000 gauss) to the exhaust jets of rocket motors in the 10,000-lb thrust class (which have been seeded with alkali atoms to the extent of 0.1 to 1.0% by mass). With the use of superconducting magnet coils, larger field strengths are possible (perhaps up to 100,000 gauss) and side thrusts of the order of several percent of the gross thrust are predicted. Because of competing factors, these control force expectations generally apply to both the equilibrium as well as nonequilibrium cases envisioned. Thirty references are included. (TPA, 1962, N62-16524)

154. PLASMA THERMODYNAMICS I: PROPERTIES OF HYDROGEN, HELIUM, AND LITHIUM AS PURE ELEMENTAL PLASMAS

McGee, H. A., Jr., Heller, G. B.

ARS Journal, v. 32, no. 2, pp. 203-215, February 1962

The problem of computing the thermodynamic properties of a plasma composed of atoms, atomic ions, and electrons has been examined from an initially rigorous point of view. Data are tabulated and comparisons made which encompass the range 2000 to 50,000°K and 100 to 0.0001 atm. (AI/S, 1962, #50,842)

155. STUDY OF ELECTRICAL ENERGY CONVERSION SYSTEMS

Sherman, A., Sutton, G. W., Smith, J. M., Robben, F.,

Zauderer, B., Blecher, S., Fried, W.

February 1962

General Electric Company, Space Sciences Laboratory, Philadelphia, Pa.

ASD TR-61-704

During the period from September 1 to December 15, 1961, a number of theoretical and experimental investigations of MHD and EHD power generation were carried out. The theoretical studies included analysis of both optimum channel configuration and optimum initial conditions for an MHD generator, as well as an analysis of the performance of an idealized EHD generator. The experimental studies centered largely on nonequilibrium ionization experiments using a plasma jet as the source of high-temperature gas. Some calculations were carried out for the constant-velocity MHD generator performance, and the investigation of an oxy-cyanogen MHD generator was initiated. (AI/A, 1962, #5591)

156. DESIGN AND OPERATION OF CONTINUOUS-FLOW ELECTRODELESS PLASMA ACCELERATOR

Barger, R. L., Brooks, J. D., Beasley, W. D.

February 1962

National Aeronautics and Space Administration, Washington, D.C.

NASA TN D-1004

An accelerator utilizing argon, or argon seeded with mercury vapor, is described. A comparison of this ac system with a dc accelerator previously investigated indicated that the induction system is more effective at pressures below 1 mm Hg. Vane deflection measurements indicated that there was effective pumping action on neutral gas. The pertinence of this accelerator to high specific impulse propulsion systems for spacecraft is discussed. (EI, 1962)

157. THEORETICAL PERFORMANCE OF A CROSSED FIELD MHD ACCELERATOR

Sherman, A.

ARS Journal, v. 32, no. 3, pp. 414-420, March 1962

A theoretical analysis, allowing for the flow of Hall currents, is presented of a crossed-field MHD plasma accelerator based on the radial source flow model in which any propellant that is a mixture of seed and inert gas can be treated.

A repetitively fired, two-stage coaxial plasma engine has been successfully operated in a 3×13 ft test chamber under conditions closely simulating those of outer space; i.e., with negligible interaction between the plasma exhaust and the residual gas. The operating principles of the two-stage engine are described in detail, along with the advantages obtained with a two-stage approach. Results of some preliminary measurements of pressure distribution in the engine, thrust, specific impulse, input mass flow, and energy efficiency are also presented.

In addition, a photoelectric spectrum mapping technique has been developed which takes advantage of the repetitive nature of the pulsed plasma exhaust. The arrangement consists of a 500-mm Ebert scanning monochromator with curved slits, a photomultiplier detector and integrating amplifier, and a strip chart recorder on which the spectra are printed. This technique has been used to obtain emission spectra from various points inside and beyond the muzzle of the two-stage gun and has been successful in yielding many more spectral lines than the standard photographic technique, to which it is compared. Generally, the results have been that only argon ion and oxygen ion lines appear in all parts of the gun and in the exhaust. Most notable in their absence are the copper and silicon ion lines, which had appeared in the exhaust of an earlier single-stage self-triggered coaxial gun and which indicate erosion of the electrodes and insulators, respectively. Ten references are included. (TPA, 1962, N62-11465)

166. PLASMA PROPULSION: AN ANNOTATED BIBLIOGRAPHY

Gex, R. C.

April 1962

Lockheed Missiles and Space Company, Sunnyvale, Calif.

6-90-62-34/SB-62-20

AD-296,344

This search references literature published during the five years prior to April 1962 concerning proposed plasma propulsion systems or devices. Review articles and reports of experimental work are emphasized. (AIA, 1963, #71,509)

167. AN EXPERIMENTAL INVESTIGATION OF A MAGNETOGASDYNAMIC ACCELERATOR

Hogan, W. T.

April 1962

Massachusetts Institute of Technology, Magnetogasdynamics Laboratory, Cambridge

Squid TR MIT-28-T-P, in cooperation with James Forrestal Research Center, Nonr-185825; Report 62-1 (Thesis), January 1962, AF 49(638)-643

AD-276,060

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Analytical studies of magnetogasdynamic accelerators illustrated a minimum power level of the order of a few tenths of a megawatt, below which the total losses were comparable

with the ideal power, and operation became marginal. The objectives of the experimental program were to achieve high levels of specific impulse and power, and to measure the overall performance characteristics of the device. A dc crossed-field accelerator was attached to the downstream end of a combustion-driven shock tube with $D = 1.5$ in., using either argon or air as the working fluid. The applied magnetic field varied from 0 to 15 kilogauss, and the electrical power from 0.5 to 11 Mw. Combined magnetic field intensity and applied current force accelerated the shock-heated gases to a maximum of three times their original velocity. (AI/A, 1962, #5620)

168. MHD-TECHNICAL TROIKA TIMED FOR LIFT-OFF

Thornton, J. A.

Naval Engineers Journal, v. 74, no. 2, pp. 349-353, May 1962

Basic principles, terminology, solution of the analytical problem, and applications of magnetohydrodynamics are discussed. The concept of magnetic containment is now applied to very high temperature plasmas which are required for controlled nuclear fusion; other applications include direct power generation and control of hypervelocity flight vehicles. Mechanical and aeronautical engineers have proposed the names magnetogasdynamics and magnetoaerodynamics; a more general and all inclusive term, magnetofluidmechanics, was suggested by Theodore von Karman and is becoming widely accepted. (EI, 1962)

169. A CLOSED LOOP MHD DEVICE WITH CESIUM SEEDED HELIUM

Emmerich, W. S., Griffith, G. L., Hundstad, R. L., Tsu, T. C., Way, S.

July 12, 1962

Westinghouse Electric Corporation, Research Laboratories, Pittsburgh, Pa.

Scientific Paper 62-118-266-P3, AF 33(657)-8311

A closed loop MHD device, consisting of a motor section and a generator section connected to end plenum passages, has been designed and partially constructed. Helium, seeded with cesium, will circulate in the loop by the driving force of the MHD motor. Power may be drawn off from the generator section while the gas is circulating so that no large gas supplies, heat exchangers, or compressors are needed. This device will be used to study the operating characteristics of the MHD motor, generating ducts, and plasma properties under long-time operating conditions, and also to study material durability under actual MHD duct conditions. (STAR, 1963, N63-11289)

170. MAGNETOGASDYNAMIC ACCELERATOR TECHNIQUES

Cann, G. L., Buhler, R. D., Teem, J. M., Branson, L. K.

July 1962

Electro-Optical Systems, Inc., Pasadena, Calif.

AEDC TDR-62-145, AF 40(600)-939

was developed enabling all calculations to be performed on an LGP 30 digital computer. These calculations are performed along a constant velocity, dc, MHD generator using stoichiometric products of hydrocarbon and air. The gas is assumed in thermal equilibrium and represented by a Boltzmann distribution so that the degree of ionization can be determined by means of the Saha equation. (AI/A, 1962, #61,395)

178. ACCELERATION OF A CONDUCTING GAS BY A TRAVELING MAGNETIC FIELD

Baranow, V. B.

ARS Journal, v. 32, no. 9, pp. 1449-1452, September 1962 (AS&T, 1963)

179. ELECTROSTATIC INSTABILITY OF A PLASMA IN A STRONG MAGNETIC FIELD

Vedenov, A. A., Velikhov, E. P.

Akademiia Nauk SSSR, Doklady, v. 146, pp. 65-68, September 1962

(Translated from the Russian in *Soviet Physics—Doklady*, v. 7, pp. 801-803, March 1963)

The problem of electrostatic instability in a completely ionized discharged plasma is investigated on the assumption that the constant magnetic field to which the plasma is subjected is intense. The ratio of the gas pressure to the magnetic pressure and the ratio of the frequency of the developing oscillation to the gyrofrequency are very small. The electric fields of the oscillations are potential fields, and there is no excitation of the magnetic field. Two equations are derived which completely determine the spectrum of plasma oscillations occurring as the result of the development of instability in a strong magnetic field. It is concluded that, as the result of the development of the instability, the spectrum of noises must be unidimensional for practical purposes. In near-longitudinal oscillations, the component of the electric field perpendicular to the magnetic field is very small. In such a case, "anomalous" diffusion of particles across the magnetic field in a slightly nonuniform plasma (due to the drift of particles in a random electric field of low-frequency oscillation) is also small; the value of the coefficient of anomalous diffusion can be found by using an expression which is provided. (IAA, 1963, A63-14152)

180. LASERS CAN AID PLASMA PROPULSION

Wiley, C. M.

Electronics, v. 35, pp. 24-26, October 19, 1962 (AS&T, 1963)

181. "COOL" METHOD OF MHD GENERATION MAY MAKE IT PRACTICAL FOR SPACE FLIGHT

Electrical Engineering, v. 81, no. 10, p. 806, October 1962

A new method is described for ionizing gases in an MHD generator by using the magnetic field already present rather than an external heat source. (AI/A, 1963, #70,456)

182. ISTECHENIE LAMINARNOI STRUI PROVODYASHCHEGO GAZA V PROSTRANSTVO S MAGNITNYM POLEM (LAMINAR JET OUTFLOW OF A CONDUCTING GAS INTO SPACE WITH A MAGNETIC FIELD)

Strakhovich, K. I., Sokovishin, Yu. A.

Akademiia Nauk Belorusskoi SSR, Inzhenerno-Fizicheskii Zhurnal, v. 5, no. 10, pp. 65-69, October 1962 (in Russian)

A method of solution of the MHD equations of velocity distribution and the longitudinal and transverse components of the magnetic field is described. (EI, 1963)

183. MAGNETOHYDRODYNAMICS

Resler, E. L., Jr.

Astronautics, v. 7, no. 11, pp. 146-148, November 1962

Since power generation is a subject of intense investigation, much concern is devoted to the various aspects of plasma physics, particularly the special effects which render the generation of power more feasible. In order to consider the various problems in their proper perspective, the overall theory of magnetohydrodynamics is briefly reviewed. (AI/A, 1963, #70,457)

184. ANOMALOUS DIFFUSION OF A LOW-DENSITY CURRENT-CARRYING PLASMA IN A MAGNETIC FIELD

Kadomtsev, B. B.

Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki, v. 43, pp. 1688-1696, November 1962

(Translated from the Russian in *Soviet Physics—JETP*, v. 16, pp. 1191-1197, May 1963)

It is demonstrated theoretically that the presence of a longitudinal current in a low-density plasma leads to a drift-wave instability. This instability is similar to the current convective instability, differing from the former only in that Landau damping replaces the finite conductivity. Since the drift waves considered go over to ion acoustic waves continuously as the angle between the wave vector and the magnetic field is reduced, it can be said that the current-convective instability and the plasma instability associated with the excitation of ion acoustic waves have been "joined." The instability considered leads to turbulent diffusion with a diffusion coefficient of the order of the Bohm coefficient. (IAA, 1963, A63-20347)

185. LONG LIFE CLOSED LOOP MHD RESEARCH AND DEVELOPMENT UNIT

December 15, 1962

Westinghouse Electric Corporation, Pittsburgh, Pa.

Interim Scientific Report 3 for September 15

December 15, 1962, AF 33(657)-8311

AD-293,438

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

density are described. At the present state of the art, this kind of accelerator appears to have a number of important potential applications, including use as (1) a source of high-speed flow for aerodynamic testing, (2) a source of high-speed plasma for research in magnetoplasmadynamics, and (3) a propulsive system for spacecraft. From the results presented and experiments described, there is positive evidence of acceleration of a plasma. It is noted that these experiments appear to be the first to have shown steady-state acceleration of a high-density plasma. (IAA, 1963, A63-14026)

190. THE DESIGN, FABRICATION, AND TEST OF A PULSED-PINCH PLASMA ENGINE FOR SPACE APPLICATIONS

Pearson, J. J., Cavalcante, C. C., Guman, W. J., Granet, I. (Plasma Propulsion Lab., Republic Aviation Corp., Farmingdale, N.Y.)
In "Engineering Aspects of Magnetohydrodynamics," Proceedings of the Second Symposium on the Engineering Aspects of Magnetohydrodynamics, University of Pennsylvania, Philadelphia, March 9-10, 1961, pp. 81-96
Mannal, C. (Valley Forge Space Technology Center, General Electric Co., King of Prussia, Pa.), Mather, N. W. (Plasma Physics Lab., Princeton University, Princeton, N.J.), Editors
Columbia University Press, New York, N.Y., 1962

A pulsed-pinch plasma device in the form of a prototype engine for space propulsion is discussed. A brief description is given of the basic features of the experimental engine (XE-1) developed by Republic Aviation, together with the major instrumentation used for the experimentation work. Application in experimental satellites is anticipated. (IAA, 1963, A63-14029)

191. MHD POWER-GENERATION STUDIES IN RECTANGULAR CHANNELS

Blackman, V. H., Demetriades, A. (MHD Research, Inc., Newport Beach, Calif.), Jones, M. S., Jr. (Allis-Chalmers Manufacturing Co., Milwaukee, Wis.)
In "Engineering Aspects of Magnetohydrodynamics," Proceedings of the Second Symposium on the Engineering Aspects of Magnetohydrodynamics, University of Pennsylvania, Philadelphia, March 9-10, 1961, pp. 180-210
Mannal, C. (Valley Forge Space Technology Center, General Electric Co., King of Prussia, Pa.), Mather, N. W. (Plasma Physics Lab., Princeton University, Princeton, N.J.), Editors
Columbia University Press, New York, N.Y., 1962

The direct conversion of thermal energy to electric energy by MHD principles is investigated experimentally. Detailed treatment is given to the following: (1) a description of the experiment; (2) the fluid dynamics, chemical kinetics, and plasma characteristics of the system; (3) theoretical consideration of MHD power generation; and (4) a description of various diagnostic systems with some of the results of the power-generation experiments. Particular attention is given to the materials problems associated with MHD power conversion. It is shown that it is possible to construct MHD power channels which stand up for greater than 10^3 sec, and

convert an appreciable fraction of thermal energy directly into electric energy. Fourteen references are given. (IAA, 1963, A63-14035)

192. A MAGNETOHYDRODYNAMIC POWER CONVERTER

Jackson, W. D., Pierson, E. S., East, D. A. (Massachusetts Institute of Technology, Cambridge)
In "Engineering Aspects of Magnetohydrodynamics," Proceedings of the Second Symposium on the Engineering Aspects of Magnetohydrodynamics, University of Pennsylvania, Philadelphia, March 9-10, 1961, pp. 294-306
Mannal, C. (Valley Forge Space Technology Center, General Electric Co., King of Prussia, Pa.), Mather, N. W. (Plasma Physics Lab., Princeton University, Princeton, N.J.), Editors
Columbia University Press, New York, N.Y., 1962

An MHD power-conversion method is proposed which uses a channeled, electrically conducting fluid, an electromagnetic pump, and an MHD generator to replace, respectively, the mechanical coupling, drive motor, and generator of a conventional rotating machine converter set. Consideration is restricted to the case of voltage transformation in dc systems, and to MHD converters in which a liquid metal serves as the working fluid. It is concluded that the velocities attainable in a practical device using liquid metal (mercury) as the working fluid, together with presently available magnetic-flux densities, limit operating voltages to the range below 10 v when the interelectrode distances are on the order of 1 m. Improvements in the fluid design and substitution of NaK as the working fluid would make the liquid-metal converter of practical interest in low-voltage, high-current systems. Ten references are given. (IAA, 1963, A63-14040)

193. ELECTROMAGNETICS AND FLUID DYNAMICS OF GASEOUS PLASMA, Proceedings of the Symposium on Electromagnetics and Fluid Dynamics of Gaseous Plasma,

New York, N.Y., April 4-6, 1961, Microwave Research Institute Symposia Series, Volume XI
Fox, J., Editor
Polytechnic Press of the Polytechnic Institute of Brooklyn, N.Y., 1962

Papers on various aspects of high-power microwave and plasma research are presented. Specific topics covered include radiation in a plasma, excitation of plasma waves by a dipole in a homogeneous isotropic plasma, interaction between slow plasma waves and an electron stream, MHD channel flow, sub-Alfvénic flow of a compressible conducting fluid, and ionization in crossed electric and magnetic fields. (IAA, 1963, A63-15809) (See Entries #194, 195)

194. THEORY AND EXPERIMENTS FOR THE ROLE OF SPACE-CHARGE IN PLASMA ACCELERATION

Hess, R. V., Burlock, J., Sevier, J. R., Brockman, P. (Langley Research Center, National Aeronautics and Space Administration, Hampton, Va.)
In Proceedings of the Symposium on "Electromagnetics and Fluid Dynamics of Gaseous Plasma," New York, N.Y.,

March 28-29, 1962)

Jones, R. E., Palmer, R. W.

1962

National Aeronautics and Space Administration, Lewis
Research Center, Cleveland, Ohio

Paper

(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Studies have been made of a traveling magnetic wave plasma engine using radio frequency excited field coils mounted co-axially about the discharge tube. The nature of the traveling magnetic wave produced by such a system has been analyzed as a function of the number of field coils, coil spacing, and the electrical phase difference between currents in adjacent coils. Based on these calculations, a preliminary four coil traveling magnetic wave plasma engine, one wavelength long, has been constructed.

Magnetic probe determinations of the experimental traveling magnetic field are presented and compared with those values of magnetic intensity obtained by theoretical analysis. The overall engine efficiency, as determined by thrust measurements, varied from 0.1 percent at a specific impulse of 150 seconds to about 1.0 percent at a specific impulse of 1000 seconds. (TPA, 1962, N62-12841)

200. ELECTRIC PROPULSION

In "1962 Proceedings of the National Aerospace Electronics Conference, May 14-16, 1962, Dayton, Ohio," pp. 608-641
Institute of Radio Engineers, Inc., New York, N.Y., 1962
(Available through NAECON, Dayton, Ohio)

The following papers are included in this section of the volume:

- "Electrodynamic Propulsion and Power Generation," by M. C. Gourdine, pp. 608-619
- "Stabilized Induction Process, Planar Mirror Drive Plasma Accelerator," by R. L. Haslund, pp. 620-625
- "Study of Plasma Mass-Velocity Distribution in Pulsed Electromagnetic Accelerator," by T. L. Rosebrock, pp. 626-634
- "Pulsed Plasma Accelerator Efficiency Improvement," by M. Maes, pp. 635-641. (EI, 1963)

201. PROBLEMES DE MAGNETODYNAMIQUE DES FLUIDES (PROBLEMS OF MAGNETOFLUID DYNAMICS) (Presented at the Third International Congress of the ICAS, Stockholm, Sweden, August 27-31, 1962)
Cabannes, H. (Faculté des Sciences de Paris, Paris, France)
1962
International Council of the Aeronautical Sciences,
c/o American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.
Paper ICAS-41

Some aspects of magnetohydrodynamics, especially those pertaining to aeronautics, are reviewed and the basic MHD equations presented and briefly analyzed. A preliminary

summary of the results of the kinetic theory applied to magnetohydrodynamics leads to a determination of the form under which it is convenient to state the physical laws governing the viscosity and the thermal and electrical conductivity of the fluid. The problem of wave propagation in the conducting fluid is studied, including simple waves and the stability and structure of shock waves. Theoretical problems posed by flow about profiles of different shapes are considered in some detail. Seventy-seven references are given. (IAA, 1963, A63-16277)

202. UNTERSUCHUNGEN AN EINER ELEKTRODENLOSEN MHD-TRIEBWERKSANLAGE (STUDIES ON AN ELECTRODELESS MHD-ENGINE DESIGN) (Presented at the Scientific Society for Aviation Annual Meeting, Brunswick, West Germany, October 9-12, 1962)
Pauer, G. (Deutsche Versuchsanstalt für Luft- und Raumfahrt, Institut für Raumfahrtforschung, Porz, West Germany)
1962
Verlag Friedrich Vieweg & Sohn, Brunswick, West Germany
Wissenschaftlichen Gesellschaft für Luftfahrt Paper 55
(in German)

The role of the electrodeless MHD jet engine is discussed, and some of the resulting problems summarized briefly. Six characteristic parts of the engine were investigated; results showed that a satisfactory general performance could be achieved only when each part was capable of high performance. Furthermore, a few of the many measurement methods, such as those for velocity and impulse (i.e., thrust measurements), are described and experimental results noted. A study of the ignition curves of various gases should lead to the determination of jet engine performance during periodical operation. (STAR, 1963, N63-10050)

203. ELECTRICAL PROPERTIES OF ROCKET FLAMES
(Presented at the ARS Ions in Flames and Rocket Exhaust Conference, Palm Springs, Calif., October 10-12, 1962)
Dimmock, T. H., Kineyko, W. R., Jen, N. (Reaction Motors Div., Thiokol Chemical Corp., Denville, N.J.)
1962
American Rocket Society, New York, N.Y.
Paper 2589-62, AF 49(604)-7284

Seeded, high-temperature flames in a rocket and on open burners were investigated to determine whether they are a suitable medium for significant MHD interactions. The plasma properties of these flames are measured by probes, microwaves, and emission spectroscopy at 0.03-16.0 atm. When the ionization of the flame is $10^{11}/\text{cm}^3$ or less, an electric-field intensity as high as 1.5 v/cm can be impressed on the plasma by external electrodes. This is enough to produce deflection of slow-moving flames in external electric fields. If the mole fraction of ionization is above 10^{-4} , the flame is unsuitable for electrostatic deflection but may be suitable for a Lorentz-field deflection. Lorentz deflection is

$I_{sp} > 5000$ sec for times of operation on the order of days; similar results at lower specific impulses are not yet available. Finally, the experimental work on the pulsed electrodeless device is described, and it is shown that, to date, relatively low efficiencies have been obtained. Some of the causes of such low efficiencies are discussed. The extension of this concept to the traveling wave machine is included, as well as 25 references. (STAR, 1963, N63-12682)

210. INVESTIGATION OF ELECTRODELESS PULSED PLASMA PROPULSION

Luce, J. S., Gates, D. C., Day, W. B., Detko, J. F., Johns, O. D., Wyatt, J. L.

February 1963

Aerojet-General Nucleonics, San Ramon, Calif.

Final Report for July 1961–November 1962 on Electrical Propulsion Technology, AN-759, ASD TDR-62-1105, AF 33(616)-8331

AD-400,459

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report is a summary of the principal results of a seventeen-month research program for the analytical and experimental investigation of electrodeless plasma accelerators as space propulsion devices. The investigation was directed toward the determination of the nature of the field-plasma interaction and the overall performance characteristics of electrodeless accelerators. Progress included the design and construction of an increasing phase velocity transmission line for the study of synchronous and induction modes of acceleration.

Measurements were made of the velocity, density, and conductivity of the plasma produced by a button source to be used with the transmission line. Diagnostic equipment was constructed for the measurement of plasma velocity, density, temperature, and conductivity. The button-type sources studied proved suitable for injecting into a transmission line and capable of producing a copper plasma with densities up to $10^{15}/\text{cc}$ and velocities in the neighborhood of 2×10^4 m/sec. Conductivities were in the range of 1000 to 1500 mho/m.

Among the principal results of the studies of the interaction of this plasma with the transmission line was the preferential trapping of plasma on the leading portion of the traveling cusp. This result was in sharp contrast to the ineffectiveness of the trailing half of the cusp to retain and accelerate the plasma. These findings support a flux trapping concept which was devised to improve the field-plasma interaction, containment and disengagement of the plasma from the traveling field at the end of the transmission line. Also, direct evidence was found for the presence of circulating Hall currents in the accelerator. Finally, there is strong evidence for the occurrence of a large-scale instability which developed in the reflected wave.

211. DENSITY FLUCTUATIONS IN A NONEQUILIBRIUM PLASMA

Salpeter, E. E.

Journal of Geophysical Research, v. 68, no. 5, pp. 1321–1333, March 1, 1963

A dilute ionized gas is considered for which electron ion collisions can be neglected and which deviates from thermal equilibrium by having an ion temperature T_i different from the electron temperature T_e . These conditions apply to the ionosphere in the F layer and above. Methods are reviewed for treating statistical mechanics at thermal equilibrium and the Boltzmann equation for general problems. The electron-electron, electron-ion, and ion-ion pair correlation functions are derived for general T_e/T_i and an arbitrary time-independent magnetic field. The total cross section for scattering of an electromagnetic wave from such a gas is derived for general T_e/T_i . The results are shown to agree with the integral of the theoretical frequency spectrum derived previously by a number of authors. For long wavelength and $T_i/T_e \ll 1$, the cross section is proportional to T_i/T_e . The sources of error for an incorrect result stated by Renau are explained. (AI/A, 1963, #71,870)

212. RAUMFAHRTFORSCHUNG BEI DER DVL IN WAHN (SPACE-FLIGHT RESEARCH AT THE DVL IN WAHN)

Europair, v. 5, pp. 76–79, March 1963 (in German)

The space-flight research work conducted at the Deutsche Versuchsanstalt für Luft- und Raumfahrt is reviewed. Specifically discussed are: (1) the application of cryogenic and cryogenic-diffusion pumps to the production of high vacuum; (2) experiments to study energy conversion for electric propulsion systems, particularly for an electrodeless plasma engine; and (3) the investigation of space-vehicle energy sources, both for nuclear propulsion systems and for auxiliary equipment. The principles of operation of cryogenic and cryogenic-diffusion pumps are outlined, and the facilities for the study of the operation of these pumps are described and illustrated. Also presented is a schematic diagram of the facility used to study electrodeless plasma systems. (IAA, 1963, A63-14901)

213. FORTSCHRITTE BEI KONTINUIERLICHEN ELEKTROMAGNETISCHEN ANTRIEBSANLAGEN (ADVANCES IN CONTINUOUS ELECTROMAGNETIC PROPULSION SYSTEMS)

Au, G. F. (Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V., Institut für Strahlantriebe, Brunswick, West Germany)

Luftfahrttechnik, v. 9, no. 3, pp. 88–94, March 1963 (in German)

The problems involved in a propulsion system composed of a plasma source and an electromagnetic post-accelerator are discussed. Twenty references are included. (AI/A, 1963, #71,717)

operating parameters, (2) the lifetime of the components for different accelerator geometries, and (3) the behavior of the working fluid. A major portion of the experimental effort was directed toward the solution of material erosion problems. A satisfactory arrangement has been devised which enables tests to be conducted with little erosion of the accelerator components at power levels up to 60 kw with mass flow rates as low as 0.3 g/sec of argon. Experiments were performed with both confined and open duct accelerators. A confined duct was operated with several gases and the relative merits of each of these gases for crossed-field accelerator application are discussed. Empirical relationships for the open duct accelerator have been obtained which describe the thrust as a function of the field parameters and the mass flow rate of the expellant. With the open duct geometry, thrusts of the order of 1 lb have been achieved with argon at $I_{sp} > 1000$ sec.

222. OPTIMUM ISOTHERMAL ACCELERATION OF PLASMA WITH CONSTANT MAGNETIC FIELD

Drake, J. H.

AIAA Journal, v. 1, no. 9, pp. 2053-2057, September 1963

On the basis of one-dimensional gasdynamics and methods of calculus of variations, a numerical solution has been obtained which, for given inlet and outlet conditions and a constant magnetic field, determines a minimum length, isothermal, crossed-field accelerator for propulsion applications. Since the results are presented in nondimensional form, it is possible to design many MHD accelerators with a variety of operating conditions. Analysis indicates that there is much to be gained from improved accelerator design. (*EI*, 1963)

223. THREE FLUID NONEQUILIBRIUM PLASMA

ACCELERATORS: PART I (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962) Demetriades, S. T., Hamilton, G. L., Ziemer, R. W., Jarl, R. W., Lenn, P. D. (Plasma Labs., Northrop Space Labs., Northrop Corp., Hawthorne, Calif.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 461-511

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

(Also available as Paper 2375-62, American Rocket Society, New York, N.Y.)

A three-fluid theory of nonequilibrium plasma flow is developed, and the underlying assumptions are discussed with emphasis on crossed-field plasma accelerators. Use is made of a simplified model of the geometry of the discharge to analyze the effect of magnetic induction on the thrust at constant total current. The mechanism of current transfer between low-temperature electrodes is also discussed. Measurements are reported of mass flow rate, thrust, axial pressure distribution, total current, electrode voltage, magnetic induction, electrode and insulator erosion, and electrode cooling rates for a continuous crossed-field accelerator. Twenty-one references are included. (*AI/A*, 1962, #60,807) (See also Entry #242)

224. EXPERIMENTAL STUDIES OF A REPETITIVELY FIRED TWO-STAGE COAXIAL PLASMA ENGINE

(Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Gorowitz, B., Gloersen, P., Hovis, W. A., Jr. (Missile and Space Div., Space Sciences Lab., Valley Forge Space Technology Center, General Electric Co., King of Prussia, Pa.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 531-542

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

A two-stage, repetitively pulsed coaxial plasma accelerator is described which was devised in an effort to minimize the switching and propellant injection problems associated with the repetitive operation of virtually all pulsed, high-current discharge plasma sources. The results of spectroscopic determination of the composition of the plasma and the time-of-flight and time contours of the various plasma species are discussed. (*IAA*, 1963, A63-25951)

225. PLASMA PROPULSION BY MEANS OF A HELICAL TRANSMISSION LINE

(Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Mayfield, E. B. (Quantum Physics Dept., Aerospace Corp., El Segundo, Calif.), Meyer, R. X. (Physical Research Lab., Aerospace Corp., El Segundo, Calif.), Head, R. M.

(Aerospace Corp., El Segundo, Calif., and Dept. of Astronautics, U.S. Naval Postgraduate School, Monterey, Calif.), Huddleston, R. H. (Theoretical Physics Dept., Aerospace Corp., El Segundo, Calif.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 543-555

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

(Also available as TDR-169(3210-05)TN-1,

DCAS TDR 62-145, July 20, 1962, Physical Research Lab., Aerospace Corp., El Segundo, Calif.; and as Paper 2378-62, American Rocket Society, New York, N.Y.)

Experimental and theoretical studies of plasma propulsion using a helical transmission line to generate a moving magnetic field were conducted. Recent development of 0.5- μ f capacitors, capable of ringing at 25 kv with a frequency of 1.05 Mc and small enough to install on a transmission line, made the construction of a 25-kv line possible. The system consists of a conical electrical discharge driver, shock tube, and helical transmission line. The propellant gas is hydrogen at an initial pressure of 175 μ (particle density 6×10^{18} cm $^{-3}$). The shock tube driver uses a capacitor bank of 8 μ f at 25 kv and rings at 250 kc. At 10 cm from the ring electrode where the shock enters the transmission line, the shock has a velocity of 16 cm/ μ sec which decays to 3 cm/ μ sec as it leaves the transmission line 115 cm from the electrode. The helical line has a phase velocity of 11.3 cm/ μ sec and a capacitance per length of 13.8 μ f/m. This gives an impedance of 0.615 Ω and an initial current of 40,700 amp. From this, the axial

Cincinnati, Ohio, October 2-4, 1962, pp. 95-113
Gordon & Breach Science Publishers, Inc., New York, N.Y.,
1963
(Also available as AD-290,074; and through U.S. Dept. of
Commerce, Office of Technical Services, Washington, D.C.)

The theory and practical effects of impulsive accelerators
are discussed. The method of acceleration, MHD instabili-
ties, and electrical parameters are described.

**231. PLASMA FLOW IN A MAGNETIC ANNULAR ARC
NOZZLE**

Patrick, R. M., Powers, W. E. (Avco-Everett Research Lab.,
Avco Corp., Everett, Mass.)
In "Advanced Propulsion Concepts. Volume 1," Proceedings
of the Third Symposium on Advanced Propulsion Concepts,
Cincinnati, Ohio, October 2-4, 1962, pp. 115-136
Gordon & Breach Science Publishers, Inc., New York, N.Y.,
1963
(Also available as AD-290,082; and through U.S. Dept. of
Commerce, Office of Technical Services, Washington, D.C.)

The performance characteristics of a magnetic annular arc
were investigated. This configuration consists of two coaxial
electrodes separated by an annular passage through which
the plasma flows with a steady solenoidal magnetic field
throughout the flow region. Initial tests at small magnetic
Reynolds number in a constant area configuration demon-
strated that the impedance of the magnetic annular arc can
be increased by a factor of 25 with the application of an
axial magnetic field between the coaxial electrodes. This
increased impedance was shown to be due to Hall currents
that flow around the annulus between the electrodes. In
addition to plasma heating, the interaction between the
plasma currents and the magnetic field has produced directed
energy comparable to the thermal energy. To exhibit thrust,
a 10-deg half-angle nozzle was added, and surveys of the
plasma properties taken at the nozzle exit are presented. A
50-deg half-angle nozzle configuration has also been studied
in which most of the plasma currents flow in the expanding
flow region. An effort has been made to produce directed
axial energy through the interaction of the circulating Hall
currents and the radial component of the magnetic field.

**232. ANALYSIS OF FACTORS INFLUENCING PLASMA-
ENGINE PERFORMANCE** (Presented at the ASME
Aviation and Space, Hydraulic, and Gas Turbine Conference
and Products Show, Los Angeles, Calif., March 3-7, 1963)
McIlroy, W., Siegel, B. (Power Conversion Div.,
Republic Aviation Corp., Farmingdale, N.Y.)
1963
American Society of Mechanical Engineers, New York, N.Y.
Paper 63-AHGT-62, Nonr-2815(00)

A method of analysis is presented for the determination
of the effects of electrode configuration and electric circuit
parameters upon the performance of a pulsed plasma pinch
engine. The equations which express the combined effect
are solved using Rosenbluth's "snowplow" model. One of the

important conclusions drawn from this solution is that the
voltage is zero, and not the current, when the convergence
efficiency is a maximum. This contradicts the usual concept
that efficiency is a maximum when plasma exits at the end
of the first half cycle. (IAA, 1963, A63-17483)

**233. CONTINUOUS PLASMA ACCELERATION AT
ELECTRON CYCLOTRON RESONANCE** (Presented at
the AIAA Electric Propulsion Conference, Colorado Springs,
Colo., March 11-13, 1963)
Hendel, H. W., Bebould, T. T. (David Sarnoff Research
Center, Radio Corporation of America, Princeton, N.J.)
1963
American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.
P63-001

Experimental and analytical results covering a continuous
method of accelerating neutral plasmas are presented. By
raising the electron energy selectively in electron cyclotron
resonance and transferring this energy to the ions by space-
charge interaction, plasma beams are produced at specific
impulses and thrusts of interest for space propulsion. In the
well-collimated plasma beam produced during the prelim-
inary experiments demonstrating the effect, a thrust of 10
dynes/cm² is measured by a mechanical vane. Mercury ion
energies from 50 to 135 ev at densities of 5×10^{10} /cm³ are
measured by means of a retarding potential-energy analyzer.
Within the present experimental limitations, good agreement
between theory and experiment is obtained. A substantial
increase in thrust density and an increase in specific impulse
appear feasible by optimization of the experimental param-
eters. (IAA, 1963, A63-15465)

234. CYCLOTRON RESONANCE PROPULSION SYSTEM
(Presented at the AIAA Electric Propulsion Conference,
Colorado Springs, Colo., March 11-13, 1963)
Miller, D. B., Gibbons, E. F., Gloersen, P., BenDaniel, D. J.
(Space Science Lab., Valley Forge Space Technology Center,
General Electric Co., King of Prussia, Pa.)
1963
American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.
P63-002, NAS5-1046
(Also available as R62SD29, Class 1, April 1962, General
Electric Co., Philadelphia, Pa.; and through the U.S. Dept. of
Commerce, Office of Technical Services, Washington, D.C.)

A plasma-acceleration system is described in which power
is transferred from an RF electromagnetic field to a flowing
plasma by electron cyclotron-resonance coupling. A highly
efficient coupling of energy from the RF field to the plasma
can be expected if a right-hand, circularly polarized wave is
used and if the flow conditions of the injected gas are prop-
erly established. Characteristics of the plasma stream as it
emerges from the resonant magnetic field are predicted by
an energy balance analysis which assumes adiabatic invari-
ance. It is shown, for instance, that a stable, longitudinal

plasma is determined theoretically. On the basis of a three-particle gas-kinetic theory, exact equations are derived for the three components of the accelerating force. The axial-force component, which is predominant, is shown to be equivalent to the electrostatic acceleration of the ions, the electrons being "trapped" by the applied magnetic field. It can also be shown to be equivalent to the Lorentz force resulting from the cross product of the Hall induced azimuthal current and the applied radial magnetic field. The mechanisms by which energy is transferred from the electromagnetic field to the gas are also studied. It is found that the energy is transmitted to the gas through the acceleration of the ions only and that the electrons do not receive any energy directly from the field. Eighteen references are included. (IAA, 1963, A63-15498)

- 239. DIAGNOSTIC STUDIES OF A PINCH PLASMA ACCELERATOR** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Duclos, D. P., Aronowitz, L., Fessenden, F. P., Carstensen, P. B. (Republic Aviation Corp., Farmingdale, N.Y.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-014A, AF 49(638)-552

The characteristics of a pinch plasma accelerator have been investigated using measurements of the total discharge current, capacitor voltage, magnetic field distribution, and light front velocity. The current distribution and $J \times B$ force on the plasma are calculated. The results show that a current sheet resulting from the first half cycle of current propagates along the electrodes, becoming more diffuse with time. It is observed that there are regions in the sheet where the direction of current density shows local reversals. Magnetic probes indicate that the motion of the current sheet turns from an initially radial to an axial direction and that the magnetic force on the current sheet is essentially in the direction of plasma motion. The impulse produced by $J \times B$ forces in the accelerator is computed and found to be about 80% of the measured thrust. All of the net energy output of the capacitor bank is transferred to the accelerator in the first 2.4 μ sec. Eleven references are given. (IAA, 1963, A63-15499)

- 240. ANALYTICAL PERFORMANCE OF A PINCH PLASMA ACCELERATOR** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
McIlroy, W. (Republic Aviation Corp., Farmingdale, N.Y.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-014B

The performance of an ideal pinch accelerator has been analyzed on the basis of a "snowplow" model coupled with

the external electric circuit. As a result, several observations are made regarding the influence of the capacitance, voltage, inductance, resistance, and density distribution on the thrust/power ratio, the maximum efficiency, and specific impulse. The qualitative trends of the theory are correlated with experiment, and indicate a direction for the design of accelerators in stipulated specific impulse, thrust, and energy ranges. (IAA, 1963, A63-15500)

- 241. AN INVESTIGATION OF A ONE KILOWATT HALL ACCELERATOR** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Brandmaier, H. E., Durand, J. L., Gourdine, M. C., Rubel, A.
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-046
AD-406,601

The steady-state, one-dimensional, inviscid magnetogasdynamic equations of flow are derived and applied to the analysis of a Hall-current accelerator. The effects of the thermodynamic and gasdynamic parameters are discussed and various flow regimes are defined. From the results of a simplified analysis, which is shown to be a good approximation to the results of this paper, a Hall accelerator design was established by maximizing the efficiency with respect to the length required for MGD interaction. The CW accelerator was designed to provide a thrust of 0.01 lbf at $I_{sp} = 2000$ sec with 1 kw of input power. Preliminary tests with this device using slightly ionized argon demonstrated that axial thrust due to Hall forces was produced.

- 242. THREE-FLUID NONEQUILIBRIUM PLASMA ACCELERATORS. PART II** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Lenn, P. D., Bodoia, J. R., Ward, D. L., Hamilton, G. L., Demetriades, S. T.
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-047
AD-406,602

The three-fluid theory of nonequilibrium plasma flow emphasizing crossed-field accelerators is extended using improved analytical models and less restrictive physical assumptions. A theory of the heat transfer to the electrodes of a crossed-field accelerator is developed which includes the effects of (1) the three-fluid behavior of the plasma, and (2) the applied electromagnetic fields. The analysis indicates that the electrical power dissipation in the electrode drop region is the major source of heat transfer to "cold" electrodes. Experimental heat transfer values were determined from calorimetric measurements on the water-cooled electrodes. Data obtained over a range of magnetic field strengths, accelerator

mental pulsed plasma accelerator (the result of five years of research on electric propulsion systems). Equations illustrating the energy storage requirements (which are determined by the power and pulse frequency), and the requirements for the propellant boiler and propellant transport, are presented. Component tests described are for propellant deposition, propellant scavenging, and fuel electrode erosion. The experimental accelerator currently approaching operational status is predicted on a power availability of 25 kw into the capacitor. Design goals for the accelerator are 50% efficiency at 3.5×10^4 m/sec velocity, and 0.7 newton of thrust at 100 pps. Thirteen references are given. (IAA, 1963, A63-18661)

**247. CONTRIBUTION Á L'ETUDE DES ACCELERATEURS
DE PLASMA Á ONDES PROGRESSIVES (CONTRIBUTION
TO THE STUDY OF TRAVELING WAVE
PLASMA ACCELERATORS) (Presented at the 14th**

International Astronautical Congress, Paris, France,
September 25–October 1, 1963)

Moulin, T.

1963

International Astronautical Federation, Paris, France

IAF Paper 114 (in French)

The advantages presented by traveling wave plasma accelerators in space propulsion are discussed. They are simple, sturdy, and permit the ejection of propellants of all types, preferably vapors of light metallic elements. Their principal drawback concerns the heat transfer at the walls. At the present state of the art, only a nuclear reactor, operating at high temperature, can supply high power in space; the outcome of the research currently carried out on plasma space propulsion depends on its construction. Twelve references are given. (IAA, 1963, A63-26007)

253. SELF-CONTAINED ION-PROPELLED ORBITAL CONTROL SYSTEMS (Presented at the Conference on Electrical Engineering in Space Technology, Dallas, Tex., April 11-13, 1960)
Walthall, E. R., Spaulding, S. W., Burrill, C. M.
December 1960
American Institute of Electrical Engineers, New York, N.Y.
T-126, pp. 130-133

For communication satellites, and for others with similar functions, station keeping is a particularly important feature. An analysis, with certain simplifying assumptions, is carried out which yields the control requirements. It is proposed that these forces be obtained by utilizing an ion motor combined with guidance instrumentation—an inertial platform and a horizon scanner, which provides the local vertical. The general merits of the ion motor and its peculiarities in this role are discussed. (EEA, 1962, #782)

254. MEGAWATT ELECTRICAL POWER IN SPACE
Ross, D. P., Ray, E., Rapp, E. G., Taylor, J. E.
Astronautics, v. 5, no. 12, pp. 26-27, 72, 74, 76,
December 1960

The need for electrical power generating units arises with the development of vehicles used as interorbital shuttles, satellite sustainers, and for lunar and interplanetary trips. A 1-Mw powerplant can supply the propulsive and auxiliary power for the round-trip transfer of a 32,000-lb vehicle from a 200-mi orbit to a 24-hr orbit using ion propulsion based on a nuclear reactor. The conceptual design, reliability and weight criteria, and two possible heat rejection systems are presented. (EI, 1961)

255. DESIGN, FABRICATION, AND TESTING OF A CESIUM ION ROCKET ENGINE
1960
Hughes Aircraft Company, Research Laboratories,
Malibu, Calif.
Quarterly Progress Report 1 for September-
November 30, 1960, NAS 5-517
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

The objective of this program is to develop a laboratory ion engine capable of producing a thrust of 0.01 lb at $I_{sp} \simeq 6000$ sec. The final unit engine will comprise two hollow cylindrical ion beams arranged concentrically with an average diameter of about 10 in. To solve preliminary engine development problems, two smaller engine models, 3A and 3B, will be used. Major accomplishment included: (1) electrode designs for four Model 3A ion engines; (2) design of a laboratory propellant feed system and fabrication of models; (3) design and construction of an ion engine test chamber, currently being installed; (4) design and testing of a thrust platform; (5) completion of a hollow-beam electrolytic tank with space-charge simulation; (6) experimental and analytical work to obtain a better understanding of the space-charge

neutralization process; and (7) start of ionizer research, including a dual-method approach to evaluation of commercially available ionizers. (TPA, 1962, N62-11120)

256. PRELIMINARY INVESTIGATION OF THE PROBLEM OF IONIC PROPULSION OF ROCKETS
Döpel, R.
Wissenschaftliche Zeitschrift der Hochschule für Elektrotechnik Ilmenau, v. 6, no. 2, pp. 125-131, 1960 (in German)

A simple, high-energy input ionic source is used to measure the reaction of emitted corpuscular rays on the source itself. The mechanism of this twin-cathode ion source reaction and the coulomb balance used in the experiments are described. Theoretical values are corrected to take care of side effects and then compared with measurements. Only a propulsion force of 28 dynes can be obtained from the experimental ionic source of 7 cm² cathode surface operated in a hydrogen atmosphere at 1300 v and 0.5 amp. It is shown that, at present, ionic propulsion is not economical when compared to conventional jet propulsion. (EEA, 1962, #783)

257. U.S. ION PROPULSION PROGRAM
Hayes, R., Seitz, R. N., Stuhlinger, E.
Astronautics, v. 6, no. 1, pp. 30-33, 90-94, January 1961

The present status of electric engine development is summarized with respect to electrostatic (ion), electrothermal (arc-jet), and electromagnetic systems. The status of the ion propulsion effort, and the already completed contracts are tabulated. Flight test plans and development projects are described. (EI, 1961)

258. HIGH-FREQUENCY ION SOURCE WITH DISCHARGE IN SALT VAPORS
Kozlov, V. F., Marchenko, V. L., Fogel, Ya. M.
Instruments and Experimental Techniques, no. 1, pp. 21-24,
January-February 1961

With the high-frequency source described, ion currents of about 1 ma were obtained. Under optimum operating conditions, an ion beam contains up to 90% of atomic metal ions. The average lifetime of such an ion source is 50 hr and the average material consumption is 30 mg/hr. (EI, 1961)

259. TWO-DIMENSIONAL ION BEAMS WITH SMALL LATERAL SPREADING
Mirels, H.
March 1961
National Aeronautics and Space Administration,
Washington, D.C.
NASA TN D-679

Ion rocket engines used as low-thrust propulsion devices are discussed assuming the flow consists of zero order due to space charge. Studies of a semi-infinite beam downstream of the ion accelerator, and of an unneutralized beam between

electron emitter to evaluate space-charge problems and optical characteristics of the systems. Ultimately, a cesium ion beam emitter will be used. Pulsed neutralization experiments will be conducted and beam diagnostic techniques will be developed to study the phenomena taking place in the neutralization zone. (TPA, 1962, N62-11311)

- 265. THRUST-MEASURING SYSTEM FOR ION ROCKET ENGINES** (Presented at the Fall Instrument-Automation Conference and Exhibit, Los Angeles, Calif., September 11-15, 1961)
Schumacher, P. E.
September 1961
Instrument Society of America, Pittsburgh, Pa.
Preprint 74-LA-61

The design and performance is described of a beam collector thrust measurement system used in a vacuum chamber with $D = 8$ in. (EI, 1962)

- 266. ION ENGINE TESTING TECHNIQUES** (Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)
Forbes, S. G., Kemp, R. F., Sellen, J. M., Jr., Shelton, H., Slattery, J. C. (Research Lab., Space Technology Laboratories, Inc., Los Angeles, Calif.)
October 10, 1961
American Rocket Society, New York, N.Y.
Paper 2183-61

The development and testing of ion engines present certain problems in measurement. The principles and methods of operation of the following three new measuring devices are described: (1) an optical probe for neutral propellant efflux; (2) an electron-beam probe for ion beam potential measurements; and (3) an electronic field strength meter for determining the floating potential of an ion engine test vehicle. (AI/A, 1962, #60,121)

- 267. A STUDY OF SYSTEMS FOR SPACE PROPULSION**
Kino, G. S.
December 1961
Stanford University, Microwave Laboratory, Stanford, Calif.
ML-873, Quarterly Progress Report 3 for August 1-October 31, 1961, NAS 8-1509
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Investigations were directed toward analytical and experimental evaluation of possible space-charge flow configurations for use in ion guns.

In determining the electrodes for a hollow-beam, axially-symmetric flow, an investigation was made of branch points because, with a previous equipotential plot, the existence of two branch points made a practical gun design impossible. In order to avoid such branch points, attempts were made to find a new flow which did not have a minimum curvature; consequently, a flow was tried in which the current density

is proportional to the radius. An electrode system was designed for this flow, which involves beam-forming electrodes, E_1 and E_2 at the potential of the emitter, an accelerating electrode, E_3 at 50 kv to accelerate the beam through a maximum of 35 kv, an outer electrode, E_4 at 17 kv, and decelerating exit electrodes E_5 and E_6 both at a potential less than the exit voltage of 6 kv. Since the electrodes were determined for only an infinitely thin beam, a theory was developed to make a first-order correction in the electrodes, due to the presence of a space charge.

Experimental work has continued on the vacuum station and cesium boiler assembly. Experiments have begun in fabricating an ion diode to develop techniques for high-temperature brazing with special alloys which do not excessively penetrate the porous tungsten emitter. (TPA, 1962, N62-11312)

- 268. DESIGN, FABRICATION, AND TESTING OF A CESIUM ION ROCKET ENGINE**
1961
Hughes Aircraft Company, Research Laboratories, Malibu, Calif.
Quarterly Progress Report 2 for December 1, 1960-February 28, 1961, NAS 5-517
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Design, fabrication, and testing of a cesium-ion rocket engine (Model 3B hollow beam) are described. The following major items were accomplished: (1) The mechanical design of the Model 3B engine was completed and several models were assembled; preliminary operational tests were conducted. (2) The neutralizer for the 3B engine was designed in the electrolytic tank and has been fabricated. (3) A neutralized pencil beam of ions was operated with a floating collector; a "false" type of neutralization was detected and investigated. (4) The ion test chamber was equipped with cryopumping and instrumentation for the 3B engine test program. (5) The laboratory cesium feed system controls were operated satisfactorily. (6) Laboratory equipment for the ionizer research program was constructed. (7) The trajectory tracer was used for studies on the Model 3B engine optics. Seventeen references are given. (TPA, 1962, N62-11122)

- 269. PHYSICS OF ION BEAMS**
Connor, R. J.
In "Proceedings, Third Symposium on Electron Beam Technology," Boston, Mass., March 23-24, 1961, pp. 89-101
Bakish, R., Editor
Alloyd Electronics Corporation, Boston, Mass., 1961

The generation and handling of intense ion beams of positive ions are discussed. (EI, 1961)

ditions prevailing in ion propulsion systems, cesium intercepted by the electrodes can accumulate and spread readily from the point of impact, thus enhancing the likelihood of voltage breakdown by spreading onto the surfaces of insulating electrode supports.

Cesium ion sputtering of electrodes in ion propulsion systems will also be investigated. The investigation will employ (1) pulsed field emission microscopy to examine sputtering effects of a cesium-ion beam impinging on a cesium-coated tungsten surface, and (2) field ion microscopy to study sputtering by alkali ions of refractory metals and to correlate ion beam energy and density to number of atoms displaced at the surface. Equipment for these studies is under construction and includes a standard field emission projection microscope, a cesium-ion source and gun, an ion collector, and a field ion microscope, which will make it possible to investigate ion sputtering on an atomic scale by permitting examination of individual atoms and their displacements of the emitter surfaces. (TPA, 1962, N62-10946)

275. DESIGN, FABRICATION, AND TESTING OF A CESIUM ION ROCKET ENGINE—PHASE II 1961

Hughes Aircraft Company, Research Laboratories, Malibu, Calif.

Quarterly Progress Report 1 for September 1–November 30, 1961, NAS 5-517

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report contains a description of all cesium ion engines and closely related work being carried out by Hughes, including both NASA contract and Hughes supported work. The principal efforts during this contract period were directed toward further preparations for the flight test, including the housing pod cover release mechanism, power supply problems, shock and vibration testing of the engine, and the engine payload interconnection and liaison problems. In addition, engine performance tests were continued, along with supporting research in beam diagnostics, neutralization, and ionizer physics. A very compact new design of ionizer heater structure was devised and tested with very encouraging results. It appears that this step will allow a substantial decrease in ionizer heating power requirements and, therefore, an increase in engine efficiency. Problems of ionizer fabrication were pursued vigorously, and encouraging preliminary results were obtained by electron beam welding and by brazing ionizers to solid tungsten support H-frames. Ten references are given. (TPA, 1962, N62-11121)

276. APPLICATIONS OF ION PROPULSION TO NASA MISSIONS (Presented at the American Rocket Society Space Flight Report to the Nation, New York, N.Y., October 9–15, 1961)

Edelbaum, T. N., London, H. S., Fimple, W. R., Gobetz, F. W.
1961 (?)

United Aircraft Corporation, Research Laboratories, East Hartford, Conn.

R-2223-61, NAS 5-935

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The following three representative missions are considered as possible applications of ion propulsion systems: a 24-hr satellite mission utilizing a first-generation (1965–1970) power supply, typified by the SNAP 8; a Jupiter probe using a second-generation (1968–1973) power supply with a specific weight on the order of 20 lb/kw and an output of hundreds of kilowatts; and a manned Mars mission utilizing a third-generation (1975–1985) power supply with a specific weight on the order of 10 lb/kw and an output of tens of megawatts. For each mission, it is shown that ion propulsion is superior to chemical-rocket, nuclear-rocket, or arc-jet propulsion systems. Thirteen references are given. (TPA, 1962, N62-11197)

277. IONTOVE RAKETY (IONIC ROCKETS)

Bláha, A.

Elektrotechnický Obzor, v. 50, no. 7, pp. 358–363, 1961
(in Czechoslovakian)

General properties of ion rockets are discussed. The ion sources are electric arc, incandescent grid, or dissociating ionic crystal. Important design problems are the compensation of charges and the compensation of electrostatic pressure. The discussion is mainly related to "slow" ion rockets with velocities comparable to but larger than those of rockets with chemical fuels. (EEA, 1962, #3740)

278. INVESTIGATION OF A 10-CENTIMETER-DIAMETER ELECTRON-BOMBARDMENT ION ROCKET

Reader, P. D.

January 1962

National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio

NASA TN D-1163

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

This report deals with an improved 10-cm-diam. electron-bombardment ion rocket capable of operation in performance regimes above 10 mlb of thrust. The source has been operated above 10 mlb of thrust continuously for 10 hr at a specific impulse of 6500 sec. The source has produced 0.5-amp beam currents at as low an impulse as 5900 sec, yielding a theoretical thrust of 13 mlb. Accelerator impingement currents have been on the order of 1 percent of the beam current. Mercury was used as a propellant during this investigation. (TPA, 1962, N62-10034)

279. PROPELLANT FEED SYSTEMS FOR ION ENGINES: THE CESIUM HYDRIDE SYSTEM

Petrick, E. N., Carter, J. C., Clark, J. C., Krauss, J. J.,

lowing five missions were included in the study: low-altitude lunar satellite; low-altitude Venus satellite; solar probe; Saturn probe; and a Jupiter satellite with a circular orbit at the altitude of Jupiter's fourth moon. The variation of payload with the ratio of power supply weight to gross weight was studied and the optimum power levels were thereby determined. The ion rocket payload capabilities were compared with those of high-thrust vehicles using hydrogen-oxygen rockets and tungsten-core nuclear rockets; in addition, the performance of high- and low-thrust systems staged in combination has been investigated. Launch vehicles considered in this study were the *Atlas-Centaur*, the *Saturn C-1*, and the *Saturn C-5*. Thirteen references are given. (TPA, 1962, N62-11131)

286. PLASMA POTENTIAL PROBE USING ELECTRON TIME-OF-FLIGHT

Slattery, J. C., Kemp, R. F.

Review of Scientific Instruments, v. 83, no. 4, pp. 463-467, April 1962

A technique is described for measuring the potential within a plasma by monitoring the time-of-flight of a beam of electrons directed through a plasma. The potential probe described was used to make comparisons among different types of ion beam neutralizers, to reveal interesting structure in potential of poorly neutralized beams, and to assess the degree to which performance of a spacecraft ion propulsion engine is affected by the insertion of material probes into the beam. (EI, 1962)

287. SISTEMI DI PROPULSIONE A IONI. I (ION PROPULSION SYSTEMS. I)

Monti, R.

Missili, v. 4, pp. 19-27, April 1962 (in Italian)

The current status of theoretical and experimental studies of ion propulsion is surveyed. Following a brief discussion of the general principles of electric propulsion as compared with conventional propulsion systems, the mechanism of ionic thrust generation is outlined. The theory of a one-dimensional beam of electrostatically accelerated ions is studied, consideration being given to the importance of propellant characteristics and to factors involved in the choice of a propellant. Problems involved in the production, acceleration, and neutralization of ion beams are covered, and different methods proposed for the solution of such problems are discussed. (IAA, 1962, #62-8210)

288. CATHODE DEVELOPMENT STUDIES

O'Leary, J. F.

May 17, 1962

Goodrich-High Voltage Astronautics, Inc., Burlington, Mass.

Final Report, NASA CR-51584, NAS 8-858

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Thermionic cathodes suitable for use in electrostatic engines as electron sources, for both injection neutralization and the arc or ionization chamber, are discussed. Topics included are general emission mechanisms, dispensation mechanisms, design criteria for optimized cathode, experimental results, and fabrication of the nickel matrix cathode. Conclusions derived from the work performed are included. (STAR, 1963, N63-22703)

289. SCALE EFFECTS ON ION ROCKET PERFORMANCE

(Presented at the National American Rocket Society-

Institute of the Aerospace Sciences Joint Meeting,

Los Angeles, Calif., June 13-16, 1961)

Reader, P. D. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

ARS Journal, v. 32, no. 5, pp. 711-714, May 1962

Two geometrically similar beam sources, with $D = 5$ and 20 cm, were scaled from a source 10 cm in diameter to allow a performance comparison. The three ion sources are compared for ion chamber characteristics and overall engine efficiency. The results of the chamber investigations are compared with scaling variations indicated by simple plasma theory. The effects of size on operating limits are also discussed. Mercury was used as the propellant. (TPA, 1962, N62-13068)

290. SURFACE DIFFUSION STUDIES OF CESIUM ON TUNGSTEN

Shelton, H.

ARS Journal, v. 32, no. 5, pp. 708-710, May 1962

Measurements were made on the angular distribution of ions radially accelerated from a tungsten wire, with $D = 0.001$ in., immersed in a cesium atomic beam. Due to surface migration, ions are emitted from the shadowed side of the wire, allowing measurements of surface diffusion length and ion lifetime under ion emission conditions and measurements of surface diffusion coefficient. Study confirms that the migration length under ion emission is indeed small and shows the importance of oxygen. (EI, 1962)

291. ION PROPULSION IN SPACE

Brewer, G. R.

American Society of Naval Engineers—Journal,

v. 74, no. 2, pp. 373-377, May 1962

The usefulness of the ion rocket as a space vehicle is discussed, and the experimental engine designed at Hughes Aircraft Company is described. In the propellant heating and storage system, cesium propellant is converted into vapor and caused to flow up to and through the ionizer and, at the surface, Cs atoms are converted to Cs ions. Positive ions are then accelerated by an electric field and are ejected through the neutralizer region. Testing information and engine diagrams are included. (EI, 1962)

to the more distant planets such as Jupiter and Saturn. Several ion rockets are currently being planned and developed for powers up to 300 kw. Problems associated with the neutralization of the charged ion beam and with instrumentation are discussed. As yet, no ion motor has been tested in flight, but it appears that the problems associated with electrostatic rocket propulsion will be solved in time to provide ion propelled spacecraft for missions taking place during the 1960s. (EEA, 1963, #5729)

299. **SISTEMI DI PROPULSIONE AD IONI. II (ION-PROPULSION SYSTEMS. II)** (Presented at the Convegno Internazionale Tecnico-Scientifico dello Spazio, Rome, Italy, June 12-15, 1961)
Monti, R. (Istituto di Aeronautica, Università di Napoli, Naples, Italy)
Missili, v. 4, no. 6, pp. 55-69, June 1962 (in Italian)

A review of ion propulsion systems is continued, with emphasis on the selection of propellants, the production of heavy particles, ion acceleration, and neutralization. Forty-one references are given. (IAA, 1963, A63-10016)

300. **PERFORMANCE EVALUATION OF A MERCURY-PROPELLANT FEED SYSTEM FOR A FLIGHT-MODEL ION ENGINE**
Pawlik, E. V., Wenger, N. C.
June 1962
National Aeronautics and Space Administration, Washington, D.C.
NASA TN D-1213

The propellant feed system, which was evaluated in vacuum facilities, consisted of an electrically heated mercury boiler and a transistorized temperature controller. The boiler was constructed with a porous plug for restricting flow of vaporized mercury and preventing liquid mercury from leaving the boiler during simulated launching. The propellant feed system was capable of reaching steady-state operating conditions after 4½ minutes of operation and of maintaining the propellant flow with 9.0% of the desired value with the ion engine operating for 30 minutes at 0.350-amp beam current. (AI/A, 1962, #60,122)

301. **ELECTRIC POTENTIAL IN A BEAM NEUTRALIZED BY NEGATIVE IONS**
Kash, S. W.
ARS Journal, v. 32, no. 7, pp. 1103-1104, July 1962

The electric potential in a positive ion beam neutralized by negative ions is compared with the earlier result on an electron neutralized beam. Since the application to electric propulsion is of particular concern, the current densities of the two sets of ion beams have been taken to be equal, although the problem can be generalized to take unequal current densities into account. (AI/A, 1962, #60,674)

302. **ELECTROSTATIC ION PROPULSION IN ATMOSPHERIC MEDIA**

Coleman, W. J.

July 1962

Grumman Aircraft Engineering Corporation, Bethpage, N.Y.

RM-210

AD-282,639

An investigation of atmospheric electrostatic ion propulsion is described. Preliminary concepts are discussed as well as results of the first series of tests. Conclusions derived from a theoretical analysis of the controlled-field section of the system are presented, and an assessment of the potential of the concept is shown to be hindered by ion current limitations. The adjection method of reinforcing the electric field to provide the required levels of ionization is discussed, and an elementary theoretical description of the adjection method is given. The adjection method is a means of increasing power extraction from an electric field by blowing ions in the direction of the field.

303. **COMPARATIVE MEASUREMENTS OF SINGLY AND DOUBLY IONIZED MERCURY PRODUCED BY ELECTRON-BOMBARDMENT ION ENGINE**

Milder, N. L.

July 1962

National Aeronautics and Space Administration, Washington, D.C.

NASA TN D-1219

Comparative measurements of singly and doubly ionized mercury produced by an electron-bombardment ion engine were made in order to obtain, in a simple and expedient manner, some indication of the degree to which multicharged ions influence the over-all performance of an electron-bombardment ion engine. (AI/A, 1962, #60,723)

304. **ATOM PROPELLED ROCKETS** (Translated from Hungarian newspaper *Technika*, v. 5, no. 10, p. 1, October 1961)

Foti, E.

Palinkas, A., Translator

July 1962

Picatinny Arsenal, Feltman Research Laboratories, Dover, N.J.

FRL-TN-104

AD-278,849

The limits of efficiency for chemically propelled rockets may soon be reached. A nuclear rocket using hydrogen as the propellant is expected to generate three times as much horsepower as its chemical counterpart. A possible future development may be the ion rocket, which would use nuclear power to produce electrical fields for the ejection of cesium ions.

305. **MATERIALS FOR ION PROPULSION**

Todd, H., Barcatta, F., Clark, D., Worlock, R.

Metals Engineering Quarterly, v. 2, no. 3, pp. 9-16, August 1962

A technical review of the analytical and experimental aspects of the ground simulation of space conditions for ion engine testing is presented; the conditions assumed to be best for simulation, and the methods of conducting the experimental studies are described. Two new probes for beam diagnostics are investigated, as well as a new technique for studies of beam interaction with the test chamber environment. Where possible, data from the new probes and techniques are included. Effects that might be produced by space phenomena on ion engine operation are discussed briefly, and the magnitude of these effects is estimated. Theoretical computer studies of the behavior of the ion beam as it leaves the engine are outlined. The results to be expected from such a program are forecast. (AI/A, 1962, #61,341)

310. HIGH EFFICIENCY LOW-PRESSURE ION SOURCE

Carlston, C. E., Magnuson, G. D.
Review of Scientific Instruments, v. 33, pp. 905-911,
September 1962
(AS&T, 1963)

311. NUMERICAL SOLUTION OF TWO-DIMENSIONAL POISSON EQUATION: THEORY AND APPLICATION TO ELECTROSTATIC-ION-ENGINE ANALYSIS

Hamza, V., Richley, E. A.
October 1962
National Aeronautics and Space Administration,
Washington, D.C.
NASA TN D-1323

The Poisson equation is solved for mixed boundary conditions by a method of successive approximations in which the differential equation is replaced by finite difference equations. Properties of the resulting matrix are studied. The Cyclic Chebyshev Semi-Iterative Method is described, and detailed calculations of ion trajectories are given. Also included is a numerical example, solved on an IBM 704 computer, for an ion rocket engine being tested at the Lewis Research Center. (AI/A, 1962, #61,336)

312. DEVELOPMENT AND TESTING OF TUNGSTEN EMITTERS FOR ION PROPULSION SYSTEMS

Gerken, J. M., Hiltz, R. H., Lally, F. J.
October 1962
Thompson Ramo Wooldridge, Inc., Cleveland, Ohio
Final Report on Metallic Materials for May 15, 1961-
July 31, 1962, ASD TDR-62-756, AF 33(616)-8297
AD-292,257
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

A process is presented for the production of porous-tungsten emitter discs with a pore spectrum of 0.7 to 0.9 μ and a mean pore diameter of 0.8 μ . Joining the emitter discs to refractory metal plenum chamber by electron beam welding

has been studied. Work was performed on both tungsten and columbium plenum chambers, and in both cases embrittlement was a serious problem. Although difficulties were encountered in successfully welding round emitters into the plenum chamber, sufficient assemblies were prepared for testing. Assemblies successfully withstood 100-hr exposure at 2500°F in a cesium atmosphere. An initial ion efficiency of 98.4% was obtained but, due to poisoning, the ion efficiency decreased with increasing time at temperature.

313. DIFFUSION BONDING TO TUNGSTEN ALLOYS

Hickox, G. K.
November 15, 1962
Aerojet-General Corporation, Solid Rocket Plant,
Sacramento, Calif.
R0433-01F, Final Report for August 1, 1961-
July 31, 1962, WAL-TR-465.54/4, DA-04-200-ORD-1077

The work performed in a study of diffusion bonding to tungsten alloys is described. The program included investigations of brazing fundamentals, tungsten forming and recrystallization behavior, brazing filler metals, and diffusion treatments. Final evaluation of the diffusion-bonding concept was made by the fabrication and firing of two solid-rocket motors with diffusion-bonded nozzles. Eleven references are included. (STAR, 1963, N63-15911)

314. THE USE OF ELECTRETS IN ELECTROSTATIC GENERATORS FOR SPACE (Presented at the American Institute of Electrical Engineers Summer General Meeting, Denver, Colo., June 17-22, 1962)

Matthew, R. E. (Aeronautical Systems Div., Wright-Patterson AFB, Ohio)
Electrical Engineering, v. 81, pp. 850-854, November 1962

Re-evaluation is now being conducted in the area of power generation and conversion from minute solar cells to nuclear power generation, in an effort to discover electric devices suitable for use in a space environment. The basic types of electrostatic generators investigated are the charge carrier, the parametric, and the electret. Size, weight, efficiency, and reliability are of major importance, since compact, efficient, high-voltage, low-current generators will be required for electric propulsion devices. A use for power sources having outputs as large as several megawatts is now foreseen. Detailed consideration is given to the electret generator, and it is concluded that, in spite of its versatility and promise, a wide range of new materials should be investigated for producing improved electrets. Graphic data are included. (IAA, 1963, A63-10711)

315. NEUTRALIZATION OF ION BEAMS FROM ENGINES OF ANNULAR GEOMETRY

Ward, J. W., Hubach, R. A. (Research Labs., Hughes Aircraft Co., Malibu, Calif.)
ARS Journal, v. 32, no. 11, pp. 1730-1731, November 1962

321. GLOW DISCHARGE AS AN ADVANCED PROPULSION DEVICE

Cheng, S.-I. (AeroChem Research Labs., Inc., and Princeton University, Princeton, N.J.)

ARS Journal, v. 32, no. 12, pp. 1910-1916, December 1962

The generation of thrust directly from electric power through a gaseous discharge is investigated theoretically with the aid of a one-dimensional model. The thrust consists of two parts: electric pressure and electric wind. In terms of the ionization constants of gases and of the mobility constants of ions and electrons, both electric pressure and electric wind are obtained in simple dimensionless form. At low gas pressures, the thrust contribution from electric pressure is usually much larger than that from electric wind. The latter may be of comparable magnitudes, or even much larger at higher (atmospheric) discharge pressures and larger interelectrode distances. The overall thrust level is proportional to the square of the gas pressure p in the discharge. For $p = 1$ mm Hg, the thrust is $\lesssim 1$ dyne/cm². The specific thrust per unit power is no greater than 10 g/kw. Thrust is derived from electric wind at a much larger specific power consumption. The low specific thrust alone rules out the possibility of using such a propulsion system as a booster. For application in outer space, it suffers from the limited specific impulse because propellant gas must be carried aboard. There may, however, be other interesting applications—e.g., as a positive control device for hypersonic vehicles at altitudes of 100,000 to 200,000 ft. (IAA, 1963, A63-11553)

322. ENERGY OBTAINABLE FROM A CARNOT ENGINE WITH A THERMALLY IONIZED GAS AS THE WORKING FLUID

Dunn, M. H., Maitland, A.

Journal of Applied Physics, v. 33, pp. 3598-3599, December 1962

(AS&T, 1963)

323. AN ELECTRON-BOMBARDMENT ION ROCKET OPERATED WITH ALTERNATING-CURRENT SUPPLIES

Reader, P. D., Finke, R. C.

December 1962

National Aeronautics and Space Administration, Washington, D.C.

NASA TN D-1457

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

Power-supply weight savings and increases in reliability may result from the operation of an electron-bombardment ion rocket on alternating current supplies instead of on the normal direct current. This approach was investigated with the alternating current effects determined for 60-cycle sinusoidal wave forms. Results indicate that a compromise system with three of the five necessary supplies operated with alternating current was competitive with total direct current operation. (AI/A, 1963, #70,125)

324. SPACE-CHARGE-FLOW THEORY AND ELECTRODE DESIGN FOR ELECTRO-STATIC ROCKET ENGINES

Lockwood, D. L., Hamza, V.

December 1962

National Aeronautics and Space Administration, Washington, D.C.

NASA TN D-1461

The basic theory of space-charge flow is described, and three general methods of solution are discussed. Specific space-charge-flow geometries are described in detail; these include paraxial flow between coaxial cylinders, concentric spheres, coaxial cones, hyperbolic flow, flow between inclined planes, and circular flow. A discussion of partial space-charge flow is presented as well as the Pierce method of electrode design. Electrode shapes for various space-charge flows are shown. (AI/A, 1963, #70,063)

325. ION PROPULSION

Stambler, I.

Space/Aeronautics, v. 38, no. 7, pp. 56-61, December 1962

The outstanding design problems are reviewed which had to be overcome in developing flyable ion engines. The two basic types of engines designed using surface and volume ionization, respectively, are compared, and the current status of four current ion-engine programs is described. Future possibilities for ion propulsion, such as colloid ionization sources, isotope engines, and controlled fusion power supplies, are covered. (AI/A, 1963, #70,430)

326. ELECTROSTATIC POTENTIAL GRADIENTS IN A NONTHERMAL PLASMA (Presented at the Union of German Physical Societies Fifth International Conference, Munich, West Germany, August 28-September 1, 1961)

Meyerand, R. G., Jr., Salz, F., Lary, E. C., Walch, A. P. (Research Labs., United Aircraft Corp., East Hartford, Conn.)

In Proceedings of Fifth International Conference, Munich, West Germany, on "Ionization Phenomena in Gases, August 28-September 1, 1961, pp. 333-342

Maecker, H., Editor

North Holland Publishing Company, Amsterdam, The Netherlands, 1962

Investigation of the existence of electrostatic potential gradients in a nonthermal plasma has shown that such gradients may exist, provided that the ion and electron velocity distributions are consistent with the condition of charge neutrality. Motion in one dimension for a collision-free plasma, as well as one in which collisions are important, is studied as a model. The solution to the equations neglecting collisions indicates that potential gradients, which, for example, trap electrons and eject ions, may exist over length scales which depend only upon the boundary conditions. Collisions, particularly ionizing collisions of electrons with a background gas, determine a length scale, and maintain the charged-particle velocity distribution required for charge neutrality.

For surface ionization as well as for surface migration, the number of available adsorption sites and the strength of adsorption at these sites is the determining factor. The coverage of 0.07 of a monolayer seems to be harder to maintain during the ionizer operation than by keeping the ionization sites underfed. In order to get high ion currents and high ionization efficiency, the front surface of the ionizer should have as large a number of ionization sites as possible. Larger numbers of adsorption sites imply larger active surface areas. It appears to be of advantage from an ionization efficiency standpoint to provide as large a number of adsorption sites on the front face of the ionizer as possible. The fine powder (as near colloidal particle size as practicable) would provide plenty of adsorption sites per unit of surface area of the macroscopic surface area and would transform the Knudsen flow into a surface migration as it reaches the ionizer front face. The use of nitrogen adsorption and desorption isotherms seems to be a straight-forward approach and, in practice, could be accomplished just as easily as measuring the flow of nitrogen gas through the ionizer at various pressures. Large flow rates of cesium vapor are possible in the event capillary condensation takes place. Twenty-four references are included. (TPA, 1962, N62-15855)

- 331. ANALYTIC SPACE-CHARGE FLOW AND THEORETICAL ELECTROSTATIC ROCKET ENGINE PERFORMANCE** (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Lockwood, D. L., Mickelsen, W. R., Hamza, V. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
1962
American Rocket Society, New York, N.Y.
Paper 2400-62
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The basic theory of space-charge flow is described, and the analytic solutions to specific space-charge flow geometries are compiled. The Pierce method of electrode design is described, and electrode shapes are determined for a number of accelerator configurations. Limitations to the theory are discussed and the theory is applied in a performance analysis of ideal electrostatic rocket engine designs based on space-charge flow geometries having analytic solutions. The relative performance and merits of the ideal engine designs are established. Thirty-four references are given. (TPA, 1962, N62-12850)

- 332. A PROPOSED ELECTRIC SPACESHIP ENGINE**
Oberth, H.
In "From Peenemünde to Outer Space" Commemorating the 50th Birthday of Wernher von Braun, March 23, 1962, pp. 377-396
Stuhlinger, E., Ordway, F. I., III, McCall, J. C., Bucher, G. C., Editors
National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Ala., 1962

An electric spaceship engine that ejects electrons and ions and creates an electric wind consisting of particles of colloidal size is presented. The operation of the engine and its various components is described. Simple methods of calculating the propulsion efficiency are presented, and losses due to dispersion, ionization, scattering, and inequalities in particle mass are considered. Useful missions for colloiddally propelled spaceships are discussed. (STAR, 1963, N63-15993)

- 333. RESEARCH ON SPUTTERING PHENOMENA, SURFACE STABILITY AND VOLTAGE BREAKDOWN FOR ALKALI-COATED REFRACTORY ELECTRODES**
Strayer, R. W., Charbonnier, F. M., Cooper, E. C., Swanson, L. W.
1962
Linfield Research Institute, McMinnville, Ore.
Quarterly Report 3 for November 1, 1961-January 31, 1962, NASr-19
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An attempt was made to (1) achieve more knowledge of the behavior of thin layers of alkali metal electrodes under conditions which prevail in ion propulsion systems, and (2) derive a better understanding and control of the processes that may lead to voltage breakdown in such systems. Absorbed cesium was removed from a low-temperature tungsten substrate by applying a strong electric field. No cesium was removed until a critical value of electric field was reached, and then the cesium coating was removed from the tungsten tip almost instantaneously. Voltage breakdown between cesium-coated tungsten electrodes was studied by direct measurement of prebreakdown gap currents and breakdown conditions. Also, cesium ion sputtering of tungsten electrodes was investigated by pulsed field emission microscopy techniques and by field ion microscopy. (TPA, 1962, N62-10372)

- 334. TRANSIENT BEHAVIOR OF PLANAR ION BEAMS**
DeGroff, H. M., Holmes, R. A. (Purdue University, Lafayette, Ind.)
In "Magnetohydrodynamics," Proceedings of the American Rocket Society and Northwestern University Fourth Biennial Gas Dynamics Symposium, Evanston, Ill., August 23-25, 1961, pp. 231-241
Cambel, A. B., Anderson, T. P. (Dept. of Mechanical Engineering, Northwestern University, Evanston, Ill.), Slawsky, M. M. (Propulsion Sciences Div., Air Force Office of Scientific Research, Washington, D.C.), Editors
Northwestern University Press, Evanston, Ill., 1962

The transient behavior of planar ion beams is analyzed following the imposition of a step-function in voltage between an emitter and an accelerating grid. This problem is associated with the successful operation of ion engines in the hard vacuum of space, which depends largely on appropriate means to effect space-charge neutralization in the ion beam. It is shown that the problem is a linear one in the Lagrangian reference frame, and solutions are provided

research on ion sources, propellant control subsystem development, power conditioning subsystem development, performance testing, and application studies. Several other areas are noted in which important developments can be expected in the near future. These include increased emphasis on life and reliability experimental evaluation, results from early flight tests of prototypes, increasing experience with system interactions and development of prototype systems, and increases in demonstrated overall performance levels. The importance and character of future work in this field is also discussed. Twenty-eight references are given. (STAR, 1963, N63-11264)

340. BEAM NEUTRALIZATION TESTS OF A FLIGHT MODEL ELECTRON BOMBARDMENT ENGINE
(Presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13-18, 1962)

Kemp, R. F., Sellen, J. M., Jr. (Space Technology Labs., Inc., Canoga Park, Calif.), Pawlik, E. V. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

1962

American Rocket Society, New York, N.Y.

Paper 2663-62

A flight test design electron-bombardment engine was the subject of a series of tests conducted to study the performance of the engine's neutralizer system under conditions simulating those which will be encountered in space. Beam diagnostic measurements have given assurance of the effectiveness of the neutralizer system. Measurements of the gross characteristics of the plasma exhaust beam have indicated that no large buildup of potential (above that of the neutralizer) occurs within the plasma because of a lack of space-charge neutralization when the neutralizer is operating in a space-charge-limited mode, *i.e.*, the ion velocity is appropriate for the net accelerating potential, electron current from the neutralizer is equal in magnitude to ion current in the beam, and additional beam divergence due to "pressure effects" of electron energy is negligibly small. Measurements of neutralizer lifetime in the presence of erosion due to ion bombardment have indicated that the present design assures a more than adequate lifetime for a space flight test. (AI/A, 1963, #70,721)

341. STUDIES OF A GAS DISCHARGE CESIUM ION SOURCE
(Presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13-18, 1962)

Speiser, R. C., Branson, L. K. (Electro-Optical Systems, Inc., Pasadena, Calif.)

1962

American Rocket Society, New York, N.Y.

Paper 2664-62

The characteristics of an electron-bombardment ion source using cesium as an expellant have been studied. The arc characteristics and operation of the source are consistent with

analytical considerations, and no anomalies were observed. Cathode configurations heated entirely by power delivered from the arc provide mass utilization efficiencies of 90% at about 650 ev/ion. In an engine configuration, this type of source has achieved overall engine efficiencies of 70 to 80% at $I_{sp} = 6000$ to 8500 sec. Attributes of the system are as follows: (1) low arc voltage; (2) low magnetic field required; (3) high mass utilization efficiency; (4) minimal, if any, secondary ionization; (5) low plasma temperature; and (6) efficient auto-cathode operation (no cathode heater power). (AI/A, 1963, #70,722)

342. ION PROPULSION FOR THE CONTROL OF STATIONARY SATELLITES
(Presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13-18, 1962)

Molitor, J. H. (Research Labs., Hughes Aircraft Co., Malibu, Calif.)

1962

American Rocket Society, New York, N.Y.

Paper 2666-62

Since one of the first applications of electric propulsion will be the attitude control and station keeping of stationary satellites, the major forces (*e.g.*, Earth's triaxiality, solar and lunar attraction, solar pressure, etc.) which tend to either perturb the satellite orbit or modify its orientation are reviewed. Mission constraints which affect the engine system design are presented. Some of the constraints considered are velocity increments associated with vernier orbit corrections, required thrusting directions, and the magnitude of disturbance torques. An evaluation is made of the trade-offs between such critical parameters as attitude and station keeping accuracy, average power utilization, duty cycle, length of thrusting interval, and satellite mass and moments of inertia. In addition, a preliminary design of an ion engine attitude control and station keeping system is given. System parameters, such as power level, thrust level, specific impulse, weight, etc., are specified. (AI/A, 1963, #70,720)

343. AN ELECTROSTATIC PROPULSION SYSTEM WITH A HIGH-FREQUENCY ION SOURCE

Löb, H.

Astronautica Acta, v. 8, no. 1, pp. 49-62, 1962

A thrust generator, consisting of a high-frequency ion source and an electrostatic accelerator, is described and test results are given. This generator weighs 150 g, delivers specific impulse between 10,000 and 20,000 sec, and has an overall conversion efficiency of from 50 to 70%. (AI/S, 1962, #51,059)

344. THEORY OF ION FLOW DYNAMICS

Samaras, D. G.

Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962

Following an examination of the historic basis of ion flow dynamics, up-to-date information on electric phenomena

5 ma with a diameter of 2.5 cm and length of 10 cm. (IAA, 1963, A63-15529)

350. EXCITATION OF ELECTROSTATIC PLASMA OSCILLATIONS NEAR THE ION CYCLOTRON FREQUENCY

Motley, R. W., D'Angelo, N. (Plasma Physics Lab., Princeton University, Princeton, N.J.)

Physics of Fluids, v. 6, pp. 296-299, February 1963

An experimental investigation of oscillations near the ion cyclotron frequency is reported. The oscillations are excited in thermal cesium and potassium plasmas by drawing current in a filament along the axis of the plasma column; they appear to be electrostatic waves propagating radially from the filament. The waves are present if the electron drift velocity exceeds about ten times the ion thermal velocity, in agreement with the prediction of Rosenbluth. The measured phase velocity is also in agreement with the phase velocity calculated from the fluid equations. (IAA, 1963, A63-13307)

351. CONDENSATION COLLOIDAL ION SOURCE

Cox, A. L.

March 29, 1963

Ion Physics Corporation, Burlington, Mass.

Progress Report No. 3 for December 1, 1962-February 28, 1963, AF 33(657)-8743

AD-402,332

A double arc arrangement with two heated filament emitters was shown to give almost four times the current obtained from a single arc. Such an ionizer can deliver up to 0.19 ma or 0.013 ma/cm² on a collector 1 3/4 in. from the throat with a -200 v bias on the collector but with no true focusing field. With a focusing field of +130 v, currents up to 5 μ a from a single arc reached a collector approximately 20 in. from the throat. Ionizers with nickel matrix cathodes suffer from heater failure and possible poisoning of the cathode. They have not produced currents greater than 0.02 μ a on the collector 20 in. from the throat. Nozzle studies of neutral flows indicated that the gas-cushioned nozzle gives better collimation than cone or bell-shaped nozzles. A shield over the throat in the ionization chamber was shown to exclude all light from the growth region, but it reduces currents to 1/60 of the unshielded value. Probe studies indicated that the beams produced by arc ionizers have high concentrations of electrons. Since these electrons interfere with growth control and may cause breakup of colloidal particles or ionization of gas in the growth region, removal of the electrons near the throat is essential.

352. ANNULAR-BEAM ION ENGINES (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Anderson, J. R., Etter, J. E., Gallagher, H. E., Ward, J. W.

AIAA Journal, v. 1, no. 3, pp. 582-586, March 1963

(Also available as Paper 2449-62, American Rocket Society, New York, N.Y.)

The strip beam, cesium contact ion engine forms a major class of electrostatic propulsion engines that develop thrust by means of the acceleration of charged particles. This strip configuration offers a number of fundamental advantages compared to other forms of ion engines, including higher current density, ease of fabrication, high overall thrust density, etc. Such ion engines, constructed in the forms of multiple linear strips and circular strip or annular configurations, have been built and operated. Some of the considerations entering into the design of efficient engines of this type are presented. Performance achieved to date on a small circular form of this strip engine is quoted, and preliminary results of some more advanced forms of engines are described. The circular strip or ring type of ion engine is emphasized, particularly one that was developed for an early flight test demonstration. Based on the experience to date, the engine's future improved performance is indicated. (AI/A, 1963, #71,402)

353. FABRICATION OF POROUS TUNGSTEN IONIZERS BY MEANS OF VAPOR PLATING (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Berkeley, Calif., March 14-16, 1962)

Gold, E. M. (Unified Science Associates, Pasadena, Calif.)

AIAA Journal, v. 1, no. 3, pp. 695-696, March 1963

The feasibility of an original method of constructing the porous-tungsten ionizer manifold assembly, used to ionize cesium for ion propulsion, is demonstrated by fabricating a tungsten manifold directly on, and integral with, the porous tungsten. The manifold is produced by vapor plating a non-porous-tungsten film from a gaseous tungsten compound. (IAA, 1963, A63-14483)

354. BEAM CURRENT MEASURING DEVICE FOR ION ENGINE RESEARCH

Domitz, S., Pawlik, E. V. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

AIAA Journal, v. 1, no. 3, pp. 712-713, March 1963

The magnetic ammeter detects the magnetic field created by the flow of charged particles and measures net dc at any position along an ion beam. In a previous study, the feasibility of this concept was demonstrated where the current of an electron beam passing through a mumetal ring with D = 6 cm was measured. This study is undertaken to determine whether a much larger instrument would have sufficient sensitivity to prove useful in ion engine research. (AI/A, 1963, #71,403)

355. NUMERICAL EXPERIMENTS WITH A PLASMA MODEL.

APPENDIX. KINETIC EQUATION FOR A SPATIALLY HOMOGENEOUS, ONE-DIMENSIONAL PLASMA

A systematic investigation of accelerator-grid-ion impingement was made with electron-bombardment ion rockets operated over a range of propellant utilization efficiencies from 0.11 to 0.95. Three ion rockets of 5, 10, and 20 centimeters in diameter were used to produce mercury-ion beams of 0.01 to 0.55 amperes at net accelerating potentials of 600 to 7000 volts. Trends of experimental impingement values were predicted by ion charge-exchange equations, particularly below propellant utilization efficiencies of 0.6. Discrepancies between experimental and predicted values were probably caused by direct impingement ions. Calculations were made to estimate the maximum lifetime of a molybdenum accelerator grid based upon the rocket operation parameters, charge-exchange equations, and the measured erosion rate of an endurance run. The experimental work was conducted in a 5-foot-diameter 16-foot-long vacuum tank. Ten references are included. (STAR, 1963, N63-15766)

362. NUMERICAL EVALUATION OF ION-THRUSTOR OPTICS
Hamza, V., Richley, E. A.
May 1963
National Aeronautics and Space Administration,
Washington, D.C.
NASA TN D-1665

A numerical solution of the two-dimensional Poisson equation with mixed boundary conditions is presented. Solution of the matrix equation by the Cyclic Chebyshev Semi-Iterative Method is described. The solution is obtained on an IBM 7090 computer. The method of analysis is demonstrated for an electrostatic thruster for four different ion-emitter contours. Average current densities and percent intercepted current are given for the four examples over a range of net- to acceleration-voltage ratios. Results of the analysis are compared with data obtained from an experimental thruster. (AI/A, 1963, #80,152)

363. AN EVALUATION OF A CESIUM ION ROCKET EMPLOYING A LARGE POROUS TUNGSTEN IONIZER (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Cybulski, R. J., Kotnik, J. T. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
AIAA Journal, v. 1, no. 6, pp. 1293-1297, June 1963
(Also available as Paper 2382-62, American Rocket Society, New York, N.Y.)

An ion rocket engine has been operated for more than 50 hr using a porous tungsten ionizer. The ionizer was assembled using the techniques of electron beam welding, combined with a high-temperature furnace braze. Accelerator and power efficiencies of 90 and 70%, respectively, were obtained at a current density of 113 amp/m². This power efficiency was obtained at $I_{sp} = 8680$ sec. Preliminary results indicate a propellant utilization efficiency of about 90%. Ten references are included. (TPA, 1962, N62-12872)

364. GRAPHICAL METHOD FOR OPTIMIZATION OF CESIUM-SURFACE IONIZER MATERIALS
Kuskevics, G. (Ion Physics Dept., Electro-Optical Systems, Inc., Pasadena, Calif.)
AIAA Journal, v. 1, no. 6, pp. 1455-1458, June 1963

A graphical method for the optimization of cesium ionizer material, structure, and operating point is presented. Proper selection of the ionizer material, its structure and work function, and the design point would optimize the propellant utilization and power efficiency, and, to some extent, life of the cesium ion engine. The method is illustrated by optimization of the design point for a solid tungsten ionizer using exponential and linearized plots, and by selection of optimum material based on preliminary experimental critical temperature curves and theoretical neutral fraction curves. (IAA, 1963, A63-18005)

365. EFFECTS OF IMPURITIES OF CESIUM FUEL UPON ION ENGINES. PART I
Merten, B. C., Skerbele, A., Bromberg, M. L.
June 1963
General Electric Company, Cincinnati, Ohio
Report for June 1, 1962-April 15, 1963, ASD TDR-63-476,
Pt. 1, AF 33(657)-9163
AD-416,449

The presence of certain impurities in cesium fuel raises the critical temperature of ionization on a particular emitter surface, thereby decreasing the thermal efficiency of the surface ionization ion engine. Critical temperature curves of cesium with selected impurities are compared to those of pure cesium on the same porous tungsten emitter surface. The effect of the impurities is then determined by a deviation in the curves.

366. RESEARCH ON EXPERIMENTAL EVALUATION OF SPUTTERING YIELD RATES
Cheney, K. B., Rogers, E. E., Pitkin, E. T.
July 1963
Marquardt Corporation, Van Nuys, Calif.
Final Technical Report, ARL-63-125, AF 33(616)-8120
AD-415,285
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Phenomena associated with the interaction of high-energy ions and solid surfaces under conditions relevant to ion rocket operation were investigated. The number of target atoms removed per incident ion, or sputtering ratio, has been determined for xenon and argon ions incident on copper, tungsten, molybdenum, silicon and titanium with energies from 1500 to 39,000 ev and at incidence angles from 2 deg to normal. The effect of both high and low target temperatures on the sputtering ratio was also investigated. The ratio of secondary particles produced to incident ions, and their energy and angular distribution, were examined as functions of ion energy and incidence angle. Areas covered include: (1) sputtering and secondary emission for very low angles of ion incidence, and effects of surface roughness; (2) the energy and

and a rectangular electrode configuration were examined for accelerator temperatures near the values yielding maximum emission. The electron-emission behavior was substantially the same for both configurations. An electron-emission current equal to about 4 percent of the ion-beam current is possible for cases where the neutral-cesium flux to the accelerator electrode comes directly from the ionizer. If a background gas pressure of cesium can build up in the interelectrode space, thermionic electron-emission currents as high as 40 percent of the ion-beam current can result. These values of electron current are of sufficient magnitude to obscure measurements of the true ion-impingement currents on the accelerator electrode. In actual thruster operation, maintaining the accelerator at a temperature $\pm 100^\circ\text{K}$ away from that at which peak electron emission occurs could reduce the electron emission current by about an order of magnitude. Twelve references are given. (STAR, 1963, N63-21890)

371. INITIAL EVALUATION OF PERFORATED ION ENGINE EMITTERS

Krauss, J. J., Petrick, E. N.

AIAA Journal, v. 1, no. 10, pp. 2393-2396, October 1963 (AS&T, 1963)

372. POTENTIALS OF RADIOISOTOPE ELECTROSTATIC PROPULSION

Mickelsen, W. R. (Electrostatic Propulsion Branch, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio), Low, C. A., Jr. (Electromagnetic Propulsion Div., Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
Astronautics and Aerospace Engineering, v. 1, no. 9, pp. 52-57, October 1963

The practical feasibility of the radioisotope electrostatic propulsion system is discussed. The problems of radioisotope availability, radiation hazards, and mating with chemical boosters are assessed, possible solutions discussed, and the potentialities of the propulsion system for future space missions estimated. It is concluded that the inherent simplicity and, therefore, expected reliability, and the potentially superior mission capability of radioisotope electrostatic propulsion systems justify further research on this propulsion concept. Ten references are included. (IAA, 1963, A63-23631)

373. ION ROCKET WITH A PERMANENT MAGNET

Reader, P. D. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

Astronautics and Aerospace Engineering, v. 1, no. 9, p. 83, October 1963

A program was undertaken to determine the feasibility of utilizing a permanent-magnet circuit to provide the magnetic field of the shape and strength required for the efficient operation of a low-current-density electron-bombardment ion rocket. Test results are presented which indicate that substitution of a permanent-magnet circuit for the field coil

produces no significant weight change, and that systems characteristics and thruster efficiency are improved through elimination of field-coil power supply and controls. (IAA, 1963, A63-23635)

374. END EFFECT CORRECTION FOR STRIP BEAM ION ENGINES

Kramer, N. B., Todd, E. G. (Research Labs., Hughes Aircraft Co., Malibu, Calif.)

Journal of Applied Physics, v. 34, pp. 3140-3141, October 1963

Brief consideration is given to electrodes designed to effect the same degree of ion trajectory control on the ends of a linear strip beam in an ion propulsion engine as along the sides of the beam, in order to minimize electrode interception and erosion. Two "end electrodes" were tested as electron gun analogs of the ion engine. A technique of space-charge simulation in a trajectory tracer is used to design focus electrodes along the length of the beam. (IAA, 1963, A63-25073)

375. COLLOIDAL ELECTROHYDRODYNAMIC ENERGY CONVERTER (Presented at the ARS Space Power Systems Conference, Santa Monica, Calif., September 25-28, 1962)

Cox, A. L. (Ion Physics Corp., Burlington, Mass.)

AIAA Journal, v. 1, no. 11, pp. 2491-2497, November 1963 (Also available as Paper 2559-62, American Rocket Society, New York, N.Y.)

The operation of a colloidal converter, its general concept and applications, and performance of the controlled-growth colloidal ion source are described. Experimental study of the formation of colloidal ions by the controlled growth process indicates that colloid energy conversion is feasible. Power losses will occur if expansion and condensation of the vapor are poorly regulated, if radiation is too slow, or if the space charge is not controlled. With proper design and selection of the working fluid, the colloid power generator should achieve 2.5 lb/kw(e) at comparatively low temperatures. The generator appears to be well suited for operation of electrostatic propulsion engines, since it directly produces high-voltage electric power. (IAA, 1963, A63-11849)

376. PLASMA BEHAVIOR IN AN OSCILLATING-ELECTRON ION ENGINE (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

Davis, J. W., Angelbeck, A. W., Pinsley, E. A. (Research Labs., United Aircraft Corp., East Hartford, Conn.)

AIAA Journal, v. 1, no. 11, pp. 2497-2504, November 1963 (Also available as P63-003, American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.)

The effect of external operating parameters, such as voltage, current, magnetic field strength, and mass flow, on the behavior of the plasma within an ion engine is investigated experimentally. Emphasis is placed on the measurement of axial plasma potential gradients. It is noted that attempts to

381. **ELECTRON BOMBARDMENT ION SOURCE** (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
French, P. (Thompson Ramo Wooldridge, Inc., Cleveland, Ohio)
In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 291-298
Stuhlinger, E., Editor
Academic Press, Inc., New York, N.Y., 1963

A mercury ion source developed for propulsive use is described. Ionization of the propellant gas is accomplished by passing the gas through a dense cloud of oscillating electrons. The motion of these electrons is constrained by electric and magnetic fields so that very high circulating electron currents are obtained in the neighborhood of the source exit aperture. The presence of the high circulating electron currents results in almost complete ionization of the propellant leaving the source, yielding very high values for propellant utilization. Further, the high utilization is obtained at discharge power inputs of only several hundred watts per ampere of extracted ion current. The primary development effort on the source has been devoted toward improvement of efficiency and propellant utilization through field and electrode geometry optimization. The level of performance obtained appears satisfactory for propulsion applications. The source aperture is in the form of a long slit of the order of 1-mm wide. This form allows considerable aperture area to be obtained while allowing close extractor electrode spacing. The close spacing permits operation at moderate extraction voltages, which is important in obtaining long engine lifetime. (IAA, 1963, A63-25940)

382. **ELECTRON TRANSFER DISCHARGE ION SOURCE** (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
MacKenzie, K. R. (Dept. of Physics, University of California at Los Angeles), Wuerker, R. F. (Applied Physics Labs., Plasma Physics Div., Quantatron, Inc., Santa Monica, Calif.)
In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 299-309
Stuhlinger, E., Editor
Academic Press, Inc., New York, N.Y., 1963

A transfer discharge ion source in which wall effects have been eliminated is described. Electrons trapped in one longitudinal electric field potential well (and longitudinal magnetic field) are transferred by a longitudinal RF field to an adjoining well, gaining energy in the process. By this technique, kinetic energy lost by inelastic collisions with neutral gas atoms is re-established cyclically; the discharge can be maintained without the aid of a thermionic source. The theory of operation is reviewed, and measurements pertaining to the question of ion production efficiency are presented. From the standpoint of ion propulsion, the transfer discharge has the feature that it does not require internal cathodes that can be sputtered away by ion bombardment. (IAA, 1963, A63-25941)

383. **IN-FLIGHT GENERATION OF FUEL FOR CESIUM ION ENGINES: THE CESIUM HYDRIDE SYSTEM** (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Petrick, E. N. (Kelsey-Hayes Co., Romulus, Mich.), Clark, J. A. (University of Michigan, Ann Arbor), Carter, J. C. (University of Pittsburgh, Pa.)
In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 311-340
Stuhlinger, E., Editor
Academic Press, Inc., New York, N.Y., 1963
(Also available as Paper 2385-62, American Rocket Society, New York, N.Y.; and through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

A study of fuel systems for cesium ion engines indicates that the generation of cesium by the thermal decomposition of the hydride offers distinct advantages when compared to the use of elemental cesium or the chemical reduction of cesium salts. The advantages include the following: less storage requirement for the propellant; density of 3.42 g/cc for CsH, as compared to 1.90 g/cc for Cs; high efficiency weight yield; 99.25% Cs generated; better 0-g operation; no liquid phase for the proposed system; and mechanical simplicity and consequent high potential reliability for the feed system. The design of a cesium hydride feed system for a particular set of conditions is described. The system utilizes no moving components other than a valve. Various aspects of the system are considered, including the chemistry of CsH, its preparation and decomposition, a method for the separation of H before passing through the emitter, and methods of flow rate control. Sufficient technological data are not presently available on all of these aspects to permit a finalized design, but the indicated advantages of the system warrant its continued investigation; a practical design appears feasible. Twenty references are given. (TPA, 1962, N62-13223)

384. **CORROSIVITY AND CONTAMINATION OF CESIUM IN ION PROPULSION** (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Holley, J. H., Neff, G. R., Weiler, F. B., Winslow, P. M. (Hughes Aircraft Co., Culver City, Calif.)
In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 341-356
Stuhlinger, E., Editor
Academic Press, Inc., New York, N.Y., 1963
(Also available as Paper 2386-62, American Rocket Society, New York, N.Y.)

Laboratory studies have been conducted to evaluate problems of corrosion associated with cesium usage in ion propulsion. An attempt has been made to establish the effect which the resultant contamination has on the cesium propellant. Research grade cesium of 99.9% (minimum) has been exposed to various contaminative materials for periods of 50 to 7000 hr at temperatures from room ambient to 1275°K. The primary contaminants detected were iron, chromium, nickel, and copper. (TPA, 1962, N62-15904)

389. LIMITATIONS ON THE SPACE TEST OF A CESIUM ION ENGINE AT ALTITUDES BELOW 1500 KM

(Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Hubach, R. A. (Electron Dynamics Dept., Research Labs., Hughes Aircraft Co., Malibu, Calif.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 587-600

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

It is demonstrated that, in a space test, there is a lower limit to the degree of electron-ion current imbalance of an ion beam which can be detected at altitudes below 1500 km. Thus, the electron and ion current emitted from the engine need not be exactly equal to prevent a net charge buildup on the vehicle. This apparently contradictory state can occur for two reasons: (1) a nebulous plasma exists in the F2 region of the atmosphere from which the vehicle can draw either electron or ion current to maintain its neutrality—the total ion current which can be drawn from such a plasma, however, being limited by the temperature and density of the plasma; and (2) the photoelectric current present when the vehicle is not shielded from the Sun will cause a net electron flux from the vehicle. The amount of beam unneutrality which is masked by the plasma current is a function of altitude and time. Curves showing this altitude dependence are presented for both the diurnal maximum and minimum of plasma density. It is found that, at the altitude and time of maximum plasma density, the beam need be only 99% neutral for there to be no charge buildup on the vehicle. At an altitude of 1500 km during the diurnal minimum, this neutralization value is improved to greater than 99.99%. Ten references are given. (IAA, 1963, A63-25955)

390. CONCEPT FOR A MANNED MARS EXPEDITION WITH ELECTRICALLY PROPELLED VEHICLES

(Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Stuhlinger, E., King, J. C. (Research Projects Div., George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 647-664

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

(Also available as Paper 2374-62, American Rocket Society, New York, N.Y.)

This paper presents a concept for a manned expedition to the surface of Mars to take place in the early 1980's. By using a fleet of five electrically propelled vehicles, high probabilities of mission success and crew safety are provided, while individual vehicle mass and complexity are kept within limits which appear reasonable for the time period considered. The five vehicles are similar in mass, design, and operating characteristics and carry three men each. Three of the five vehicles carry high-thrust landing craft for transportation between the orbiting electric ships and the Martian surface. The other

two carry compensating amounts of propellant during the outbound portion of the interplanetary journey. Since no landing craft are carried on the Earth-bound leg, the propellant loadings are equalized between the five electric vehicles before departing from the Mars satellite orbit. The vehicles are assembled in low-altitude orbits around Earth and travel together to Mars. After they have been guided into similar orbits about Mars, the first landing craft, which carries only equipment and supplies, is dispatched. The second craft then follows, carrying a small crew. The third landing craft is held as a backup for the second; any of the three is capable of returning the landing crew to the orbiting electric vehicles.

A constant, slow rotation of the large vehicles is maintained throughout the journey to provide a simulated gravity environment in the crew compartments. Each crew compartment contains a heavily-shielded radiation shelter, to be occupied during passage through the inner Van Allen belt and during periods of intense solar activity. The compartment and shelter of each vehicle are large enough to accommodate additional personnel, and even the entire expedition crew of 15 men, in case of an emergency return to Earth. The main vehicles are powered by fission reactors, from which electric power is derived by turbogenerator, thermionic, or plasma dynamic conversion techniques. The electrostatic thrust devices operate under constant conditions but are programmed in direction during the interplanetary transfer. Details on the flight plan, as well as conceptual design data on the vehicles, are presented in the text. Ten references are given. (TPA, 1962, N62-13074)

391. ION PROPULSION. AN INTRODUCTION TO THE GENERAL PROBLEMATICS OF THE ION ROCKET ENGINE

Nagy, E. (Institute of Theoretical Physics, Budapest Science University, Hungary)

In "Proceedings of the International Congress—Man and Technology in the Nuclear and Space Age, 40th Trade Fair, Milan, April 18-21, 1962 (Rendiconti del Congresso Internazionale—L'Uomo e la Tecnica nell'Era Nucleare e Spaziale, 18-21, Aprile 1962)," pp. 245-251

Associazione Internazionale Uomo nello Spazio, Rome, Italy, 1963

This paper deals with some general aspects of ion propulsion, rather than with specific problems of ion rocket engine development. (STAR, 1963, N63-18925)

392. THE ELECTRON-BOMBARDMENT ION ROCKET

Kaufman, H. R. (Electrostatic Propulsion Systems Section, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)

In "Advanced Propulsion Concepts. Volume 1," Proceedings of the Third Symposium on Advanced Propulsion Concepts, Cincinnati, Ohio, October 2-4, 1962, pp. 3-18

A procedure is described by which a high current, space-charge neutral ion beam may be generated and accelerated electrostatically by self-generated electrostatic potential gradients within a nonthermal plasma. In the oscillating-electron ion engine, the ions are produced by electron collisions with a neutral gaseous expellant, and the nonthermal electron energy distribution results in the maintenance of the electrostatic potential gradients over large length scales. As a consequence of the unique method of ion acceleration, the ion current is not limited by space-charge considerations. Therefore, thrust may be generated in the important specific impulse range of 1000 to 5000 sec without suffering the reduction in thrust density usually associated with low accelerating voltages. (IAA, 1963, A63-25816)

398. NASA RESEARCH ON HEAVY-PARTICLE

ELECTROSTATIC THRUSTORS (Presented at the IAS 31st Annual Meeting, New York, N.Y., January 21-23, 1963)
Mickelsen, W. R. (Electrostatic Propulsion Branch, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
1963
Institute of the Aerospace Sciences, Inc., New York, N.Y.
Paper 63-19

The NASA research program on heavy-molecule and colloidal-particle spacecraft thrusters is described. Some preliminary results relating to fragmentation and multiple ionization of the propellant molecules in experimental heavy-molecule engines are presented. Recent experimental findings are outlined regarding the colloidal-particle thruster. The generation and charging of colloidal particles, in particular, is considered. Mission analyses indicate that considerable loss in payload or increase in mission time may result from thruster inefficiency or from operation at an off-optimum specific impulse. The excellent vehicle performance possible with the Irving-Blum trajectory (variable specific impulse) constitutes one justification for research leading to thrusters with high efficiency at a specific impulse as low as 2000 sec. Preliminary experiments with a number of heavy-molecule propellants indicate that fragmentation and/or multiple ionization in the electron-bombardment ionization chamber may be a serious problem. Limited data also show that this problem might be overcome by changes in thruster design or thruster operating conditions. Fifteen references are given. (IAA, 1963, A63-11268)

399. TEST RESULTS FOR A CESIUM ELECTRON

BOMBARDMENT ION MOTOR (Presented at the IAS 31st Annual Meeting, New York, N.Y., January 21-23, 1963)
Speiser, R. C., Kilpatrick, W. D., Reid, G. R. (Electro-Optical Systems, Inc., Pasadena, Calif.)
1963
Institute of the Aerospace Sciences, Inc., New York, N.Y.
Paper 63-75, NAS 8-2511

An experimental investigation of electron-bombardment ion motors, using cesium as an expellant, is reported. The

discharge and engine characteristics are studied. Cathode configurations heated entirely by power delivered from the arc provide mass utilization efficiencies of 90% at 650 ev/ion. The engines achieved overall efficiencies of 70-80% at $I_{sp} = 6000-8500$ sec and thrusts up to 0.01 lb. (IAA, 1963, A63-14602)

400. UTILIZATION OF ELECTRIC THRUST DEVICES

FOR SPACECRAFT PROPULSION (Presented at the ASME Hydraulic and Gas Turbine Conference and Products Show, Los Angeles, Calif., March 3-7, 1963)
Molitor, J. H. (Research Labs., Hughes Aircraft Co., Malibu, Calif.)
1963
American Society of Mechanical Engineers, New York, N.Y.
Paper 63-AHGT-46

The utilization of electric thrust devices for interplanetary spacecraft is discussed. Two missions, a Mars orbiter and a Venus orbiter, are analyzed to determine the requirements placed on an electric propulsion system by interplanetary spacecraft. Terminal mass-to-initial mass ratios are presented as a function of total flight time with initial acceleration and specific impulse as parameters. The mission requirements are then translated into desired engine-performance characteristics. A description of a cesium-surface, contact-ion thrust device is given, and the power efficiencies of present and advanced engines are presented as a function of specific impulse. The optimum specific impulse, as well as the required power-to-thrust ratio for each mission, is then defined. In conclusion, the weights and sizes of ion thrust modules are estimated, and possible module arrays meeting spacecraft integration requirements are discussed. (IAA, 1963, A63-17670)

401. COMPARISON OF COMMERCIAL, SPHERICAL POWDER AND WIRE BUNDLE TUNGSTEN

IONIZERS (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Kuskevics, G., Thompson, B. L. (Electro-Optical Systems, Inc., Pasadena, Calif.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-016, AF 33(616)-6958
AD-407,766

Cesium ionization on different porous-tungsten structures was measured in terms of neutral fraction, critical temperature, and flow rate in a regular laboratory test chamber environment in the 10^{-6} torr range. These structures included 3/16-in. commercial-sintered ionizers with about 2μ average pore diameter, and wire bundle ionizers 12 and 6μ in diameter. Conductance was measured at room temperature with nitrogen, and at operating temperature with cesium vapor. The angular distribution of cesium atom efflux in the non-ionizing state without accelerating voltage was assumed to be the same as that of the neutral efflux in the ionizing state

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.
P63-029

The performance of an experimental contact-ionization thruster with cesium propellant is discussed. The porous-tungsten ionizer is of cylindrical-concave shape to minimize impingement. The ion thruster employs focusing electrodes and an accelerating electrode positioned at accelerating distances of 2.00 and 2.50 mm. Current densities as high as 260 amp/m² are obtained with accelerator currents of 15% of the ionizer current. No recordable accelerator electrode current is obtained for ionizer current densities less than 70 amp/m² for an accelerator length of 2.00 mm and net accelerating voltages greater than 4 kv. A comparison is made between the experimental data and the results obtained from a numerical solution of the two-dimensional Poisson equation. Theoretical ion trajectories for a number of configurations are presented. Fourteen references are given. (IAA, 1963, A63-16662)

406. STUDIES OF A LEWIS TYPE BOMBARDMENT ION ENGINE. (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
King, H. J., Quintal, B. S. (Ion Physics Corp., Burlington, Mass.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-030A, NAS8-1684

Experimental results on the performance of a Lewis-type electron-bombardment ion engine are evaluated. It is found that, depending on the fixed operating parameters, either the arc density or the beam-forming electrode geometry limits the allowable output current. A similar type of operation is found for engines varying in diameter by a factor of three, indicating that the engine size may be scaled if required to produce a particular output thrust or to match the power output of a generator. Thrust pulses of 50-msec duration have been produced with a rise time of the order of 10 μ sec by pulsing the arc voltage. No deleterious effects are observed as a result of operating the engine in a pulsed mode. A cutaway drawing of the engine is included. (IAA, 1963, A63-16661)

407. ANALYTIC CONSIDERATIONS RELATED TO THE LEWIS TYPE BOMBARDMENT ION ENGINE (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Kohlberg, I. (Ion Physics Corp., Burlington, Mass.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-030B, NAS8-1684

An exploratory, theoretical model was developed to determine the regions of weak and strong plasma; in addition, it was used to predict the radial shape of both plasma density

and electrostatic potential. The electron distribution function was calculated for Hg under an assumed weak plasma condition, which showed that the electron temperature T_e varied as $(E/B)^2$ with estimated values ranging from 250,000 to 400,000°K. At times, experimental results gave a slight increase of T_e with B , with measured values in the 60,000 to 90,000°K range. Consequently, based on this variance, it was concluded that the arc did not operate as a weak plasma. The kinetic model for the arc utilized both a primary electron group and a Maxwellian group which evolved from ionization and elastic slowing down of the primaries. The radial potential $V(r)$ and plasma density $N(r)$ were calculated by developing a modification of ambipolar diffusion theory. The results gave $N(r) = N_0 J_0(\gamma r)$, and $V(r) = V_0/nN + \text{constant}$, where γ depends upon a number of operational parameters. It was found that relatively small adjustment in the calculated value of γ could bring the theoretical and experimental $N(r)$ into agreement for average plasma densities greater than 10^{11} cm⁻³. The uncertainties in the measurement of $V(r)$ precluded comparison of this quantity. (STAR, 1963, N63-17659)

408. AN ELECTRON-BOMBARDMENT ION ROCKET WITH A PERMANENT MAGNET (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Reader, P. D. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-031

An experimental investigation was conducted to determine the feasibility of utilizing a permanent magnet circuit to provide the magnetic field of the shape and strength required for the efficient operation of a low current density, electron-bombardment ion rocket. The method used to design the magnetic circuitry is described. Ion-chamber efficiency is compared experimentally between the permanent magnet and solenoid types, and flight-type designs for both magnetic-field systems are compared for total weight and system requirements. It is found that the permanent-magnet circuit is a reliable, mechanically strong, efficient replacement for the solenoid on the electron-bombardment thruster. The circuit can be designed to yield total thruster weights comparable to units with flight-weight solenoid coils, in addition to eliminating the weight of the power supply and controls required by the field windings. The permanent magnets serve as a return path for the magnetic flux lines, which substantially reduces the field external to the thruster. (IAA, 1963, A63-17220)

409. ION ENGINE RELIABILITY AS AFFECTED BY CORROSION OF MATERIALS (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

associated with the choice of Cerium-144 as the fuel for radioisotope electrostatic propulsion systems. It is shown that the anticipated availability of Cerium-144 as a by-product from ground-based power reactors will be sufficient for propulsion systems of 10 to 50 kw(e) in 1965, and 100 to 500 kw(e) in 1980. The cost of the radioisotope is estimated to be \$30,000 per kw(e) as a power reactor by-product in 1965. The payload radiation dose caused by Cerium-144 electrogenerators is shown to be within acceptable limits even without shielding. The radioisotope electrostatic propulsion system is of sufficiently small size for convenient mating with chemical boosters such as the *Atlas-Agena* and the *Centaur*. The theoretical performance of the radioisotope system on space probe missions such as Mars and Saturn orbiters is much superior to other propulsion systems. Ground handling and launch-pad radiation hazards are serious problems, but it appears that the radiation dosage can be reduced to safe levels with simple shielding. Boost-phase radiation hazards are serious and have not been examined in detail. A cursory analysis shows that the use of the Cerium-144 system for manned interplanetary flight may be possible. Massive components such as solar-flare shelters and/or propellant appear to be adequate for shielding the crew from the Cerium-144 gamma radiation. Ten references are included. (IAA, 1963, A63-16896)

414. **THE CONTROLLED-GROWTH COLLOIDAL ION SOURCE** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Cox, A. L., Harrison, S. (Ion Physics Corp., Burlington, Mass.)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-049, AF 33(657)-8743

For propulsion purposes, a colloidal ion source should produce particles with a very limited spread of charge-to-mass ratios between 10^2 and 10^5 coulomb/kg at current densities of at least 0.1 ma/cm^2 . To meet these requirements, the controlled-growth colloidal ion source was planned to provide for growth of ions by condensation from an accompanying supersaturated vapor. Growth of the colloidal ions is controlled by a retarding field which governs the velocity of the charged particles through the growth region. Although the processes involved in the controlled-growth colloidal ion source are interdependent, initial experimental studies were necessarily confined to separate investigations of ionization and mass flow. Useful studies of the growth process require a partially ionized, supersonic, supersaturated jet. Several ionization techniques were evaluated under the conditions required for operation of the controlled-growth colloidal ion source. The ability of various nozzle designs to produce a collimated jet of vapor was also studied. In some experiments, the presence of electrons in the growth region and the effects of retarding and focusing fields on the ion beam were examined. The nucleation process, which must

precede particle growth, was analyzed. This analysis indicates that mercury may best achieve the required preferential ion nucleation. Sixteen references are given.

415. **THRUST MEASUREMENTS OF COLLOIDAL PARTICLES AS AN INDICATION OF PARTICLE SIZE AND THRUSTOR OPERATION. APPENDIX. APPROXIMATION OF SURFACE TENSION VALUES** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Goldin, D. S., Norgren, C. T. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-050

Thrust measurement and its correlation to the operational characteristics of an experimental colloidal-particle thruster are discussed. Measurements are made on a previously designed condensation colloidal-particle electrostatic thruster with mercurous chloride as the propellant. Thrust measurements of the order of 1 to 10 mg are made with a modified electric microbalance calibrated to a sensitivity of 10^{-4} to 10^{-5} g. As anticipated from the classical liquid-drop theory of nucleation, no thrust is observed until a viscous flow regime and, subsequently, a critical nucleation rate is obtained in the nozzle. This condition corresponds to a vaporizer temperature of 485°K . With the assumption of singly-charged colloids, it is determined that a mean particle size of 1.2×10^6 atomic mass units would be required to account for measured target deflections at a vaporizer temperature of 490°K . From an electron photomicrograph of the colloidal beam at similar operating conditions, a mean particle size of 1.71×10^6 atomic mass units is indicated. Twenty-one references are given. (IAA, 1963, A63-16899)

416. **PHOTOMICROGRAPHY OF ELECTRICALLY SPRAYED HEAVY PARTICLES** (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)
Hendricks, C. D., Jr., Carson, R. S., Hogan, J. J., Schneider, J. M. (University of Illinois, Urbana)
1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-051, AFOSRG 107-63, NSF G-19776

Charged-droplet production and behavior are studied, including the effects of such physical properties as density, viscosity, conductivity, and surface tension on the charge-to-mass ratio distribution. High-speed photomicrographs of surface instabilities are presented and discussed, and Rayleigh's theory on the instability of charged droplets is extended to include droplet emission. (IAA, 1963, A63-16900)

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.
P63-273, NAS3-2510

The results of a study concerning the magnitude and nature of the major forces (*e.g.*, solar-lunar and Earth's tri-axiality) which perturb the orbit of a synchronous satellite are presented. From these results, the optimum design and mode operation of an ion propulsion, station-keeping system are determined. A comparison of the system weight for both pulsed-mode and continuous-mode operation shows the distinct advantage of a continuous correction with a relatively low-thrust ion engine. Tradeoffs between the critical mission and system parameters are provided from which the capabilities and requirements of both the attitude-control and station-keeping systems can be determined for application over a wide range of satellite weights. (IAA, 1963, A63-18760)

422. IONISATION OF CESIUM ON POROUS TUNGSTEN
(Presented at the 14th International Astronautical Congress,
Paris, France, September 25-October 1, 1963)
Forrester, A. T., Kuskevics, G., Marchant, B. (Electro-
Optical Systems, Inc., Pasadena, Calif.)
1963
International Astronautical Federation, Paris, France
IAF Paper 115, AF 33(657)-8157, AF 33(657)-10980

An analysis (by means of an ion-emission microscope) of cesium ion emission from porous tungsten ionizers is presented. The previous analyses of the porous ionizers are reviewed and some of their simplifying assumptions are eliminated. The study is conducted to make possible quantitative evaluations of ion engine performance which can be anticipated for various porous structures. Fourteen references are included. (IAA, 1963, A63-25659)

423. DENSITY-TIME PROFILES FOR AN ELECTRIC
PROPULSION UNIT EFFLUX
McNab, I. R., McNeill, P. C.
1963

International Research and Development Company, Ltd.,
Great Britain
Research Report
AD-413,509
(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

The initial particle densities obtained from present electrical propulsion units indicate that, at altitudes between 50 and 200 mi, the decay of density in the efflux may be obtained using a diffusion approach; numerical density-time profiles are given. When initial particle densities are less than 10^{12} ions/cc, the effects of recombination and ionization are shown to be negligible, the efflux remaining fully ionized. The results are compared with those obtained by Molmud for free molecular flow and the difference between the two approaches is explained. The effects of such highly ionized exhausts on radio communications between space vehicles and ground stations are discussed.

424. THEORETICAL PERFORMANCE OF ELECTRO-
STATIC THRUSTORS WITH ANALYTIC
SPACE-CHARGE FLOWS
Mickelsen, W. R.
1963
National Aeronautics and Space Administration,
Washington, D.C.
NASA TR R-174

An electrostatic thruster converts electric power into thrust by accelerating ions to the exhaust velocity specified by vehicle design parameters and mission analysis. The parameters derived are exact, in closed form, directly related to mission analysis and powerplant design parameters, and apply to contact ionization and electron bombardment thrusters. Analysis of space-charge flow geometries shows that divergent cylindrical, divergent spherical, and circular flow geometries have the most promise for contact ionization thrusters. Twenty-seven references are given. (EI, 1963)

hood of the cathode. This breakdown occurs at abnormally low voltage differences; the evidence indicates that the breakdown is strongly affected by the aerodynamic characteristics of the flow around the cathode. A model of the entire process is proposed which sheds new light on the stability of high-pressure plasma arc devices and emphasizes the dynamic characteristics of the dc power supply. Reduced data for arc velocity, cycle time, voltage fluctuations, and time-average arc characteristics are presented for nitrogen. (TPA, 1962, N62-12141)

431. **FOUNDATIONS OF ENGINEERING MAGNETO-HYDRODYNAMICS** (Presented at the First International Congress and Exposition of Automotive Engineering, Detroit, Mich., January 9-13, 1961)
Cambel, A. B.
1961
Society of Automotive Engineers, Inc., New York, N.Y.
Paper 312A

Engineering magnetohydrodynamics is defined and its application to materials science, flow control, aerodynamics containment, propulsion, and power generation outlined. The thermophysical properties of plasmas, essentials of electromagnetism, and equations of magnetogasdynamics are presented, with experimental observations in magnetohydrodynamics and its applications. (EI, 1961)

432. **DESIGN ASPECTS OF ELECTROTHERMAL PROPULSION SYSTEMS**
Spongberg, R. M.
In "Proceedings of the National Aerospace Electronics Conference, Dayton, Ohio, May 8-10, 1961," pp. 532-543
Institute of Radio Engineers, Inc., New York, N.Y., 1961
(Available through NAECON, Dayton, Ohio)

The operating principles of several basic electrothermal rocket concepts are reviewed. Important design features of devices such as the arc jet, resistance jet, inductive jet, and magnetic interaction jet are discussed. The relative advantages of various schemes are presented, and basic problem areas are described in detail for each type of device. Twenty-nine references are included. (EI, 1962)

433. **REGENERATIVE AND RADIATION COOLING OF ELECTROTHERMAL THRUST GENERATORS** (Presented at the Institute of the Aerospace Sciences-ARS National Meeting, Los Angeles, Calif., June 13-16, 1961)
Jack, J. R.
1961
American Rocket Society, New York, N.Y.
61-97-1791

A general discussion of the effects and limitations of regenerative and radiation cooling on electrothermal thrust generators is presented. In particular, the possibility of cooling a 30-kw(e) arc jet operating at about 1-atm pressure is discussed.

434. **ENERGY TRANSFER TO PLASMAS BY CONTINUOUS LORENTZ FORCES**
Demetriades, S. T., Ziemer, R. W. (Norair Div., Northrop Corp., Hawthorne, Calif.)
In "Magnetohydrodynamics," Proceedings of the American Rocket Society and Northwestern University Fourth Biennial Gas Dynamics Symposium, Evanston, Ill., August 23-25, 1961, pp. 185-205
Cambel, A. B., Anderson, T. P. (Dept. of Mechanical Engineering, Northwestern University, Evanston, Ill.), Slawsky, M. M. (Propulsion Sciences Div., Air Force Office of Scientific Research, Washington, D.C.), Editors
Northwestern University Press, Evanston, Ill., 1962
(Also available as Paper 2002-61, American Rocket Society, New York, N.Y.)

An experimental and theoretical investigation of the acceleration of a plasma stream by means of crossed electric and magnetic fields is presented. Equations are given for the thrust and efficiency of a Lorentz accelerator, in terms of easily-measured parameters. Studies with a continuous Lorentz accelerator, using an arc-jet plasma source and argon and nitrogen expellants, show that, with artificial cooling of the electrodes, such an accelerator should be an efficient propulsion device. Direct-thrust measurements show acceleration efficiencies as high as 42%. Twelve references are given. (IAA, 1962, #62-815)

435. **ARC JET ENGINE PERFORMANCE—EXPERIMENT AND THEORY. III** (Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)
John, R. R., Chen, M. M., Connors, J. F., Hoercher, H. E. (Research and Advanced Development Div., Avco Corp., Wilmington, Mass.)
1961
American Rocket Society, New York, N.Y.
Paper 2135-61

The status of a continuing effort for the analytical and experimental determination of arc-jet performance is reported. Experimental results are presented concerning the operation of a lightweight diode-rectifier combination suitable for converting three-phase 1000 cycle ac to dc. A transient thermocouple technique for measuring arc engine internal heat-transfer distributions is described. Static pressure distributions obtained along an arc engine exit nozzle suggest that the "effective" nozzle area ratio is smaller than the geometrical area ratio. A design study has been carried out to determine the feasibility of a 10-min flight test of a 3-kw radiation-cooled arc-jet engine. (AI/A, 1962, #61,653)

436. **ERZEUGUNG VON PLASMASTRAHLEN HOHER TEMPERATUREN UND GESCHWINDIGKEITEN (GENERATION OF PLASMA JETS HAVING HIGH TEMPERATURES AND VELOCITIES)**
Peters, T.
Astronautica Acta, v. 7, no. 2-3, pp. 150-170, 1961

An electrothermal propulsion device based on the principle of heating a propellant by convection heat transfer from refractory, resistance elements is described. The thermal energy in the propellant is converted to directed kinetic energy by expansion through a nozzle. It is shown that rockets using this principle can attain overall efficiencies in excess of 70%, and $I_{sp} = 1000$ sec. (IAA, 1962, #62-8207)

445. FEASIBILITY OF ARCJET-PROPELLED SPACECRAFT

Yarymovych, M. I., deWiess, F. A., John, R. R.
Astronautics, v. 7, no. 6, pp 36-42, June 1962

Of the proposed electric propulsion schemes—including electrothermal, electrostatic, and electrodynamic devices—electrothermal arc jet appears closest to the actual system. Its basic components are the cathode, the anode, and the exit nozzle. The typical 30-kw radiation cooled engine design considered is based on the constricted-arc configuration. The arc-jet mission that shows greatest promise is the 24-hr communication satellite. A circuit diagram of the electrical conversion system for a 30-kw arc-jet engine is presented, and launch packaging techniques for arc-jet spacecraft designs are indicated. (EI, 1962)

446. SOME GAS DYNAMIC CHARACTERISTICS OF ARGON PLASMA—APPLICATION TO JET SPREADING

Tempelmeyer, K. E., Dicks, J. B.
July 1962

Arnold Engineering Development Center, Arnold Air Force Station, Tenn.

AEDC TDR-62-88, AF 40(600)-1000
AD-277,443

(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

Jet-spreading characteristics of a low-temperature argon plasma expanding from a sonic nozzle into still air at pressure ratios up to 18 are described. The argon plasma exhibited about the same jet-spreading behavior and jet structure as cold argon when the two jets were compared at the same nozzle operating pressure ratios. Approximate calculations indicate that electromagnetic forces on the plasma were insignificant for these tests. Gas dynamic and heating analyses of plasma flows are suggested as a means of estimating effective thermal properties of the plasma and studying the overall energy exchange process. Seventeen references are included.

447. THE PERFORMANCE AND TEMPERATURE OF A GASEOUS NITROGEN STABILIZED ARC PLASMA GENERATOR

Brewer, L. E., McGregor, W. K., Dooley, M. T.
August 1962

ARO, Inc., Tullahoma, Tenn.

AEDC TDR-62-113, AF 40(600)-1000

A dc, arc-excited plasma generator, designed and fabricated at the Rocket Test Facility, Arnold Engineering Cen-

ter, is described. The operating characteristics (voltage vs current, power vs increase in enthalpy, and efficiency) are discussed. For this generator, applied power ranged from 10 to 40 kw, which changed the gas enthalpy by as much as 1100 kcal/kg up to 2300 kcal/kg. A spectrometric temperature measuring method is presented, as well as the plasma stream temperature profile as determined by the method. Nitrogen was used exclusively as a working fluid. Twelve references are given. (TPA, 1962, N62-16716)

448. THEORETICAL AND EXPERIMENTAL RESEARCH ON THERMAL ARC JETS

Chen, M. M., Connors, J. F., John, R. R.
August 1962

Avco Corporation, Research and Advanced Development Division, Wilmington, Mass.

Final Report for July 1961–May 1962, ASD TDR-62-616,
AF 33(616)-8504

A combined experimental and analytical program compared direct and single-phase ac arc-jet engine performance and studied scaling and heat-transfer relations for a series of dc arc-jet engines. Engine propulsion performance measurements are given for a hydrogen radiation-cooled arc-jet engine operating on both single-phase ac (1000–1500 cps) and dc power over the range 20–50 kw. Results are presented for experimental scaling and heat-transfer studies on three different dc hydrogen, radiation-cooled arc-jet engines having nominal power ratings of 5, 30, and 50 kw. (AI/A, 1962, #61,680)

449. BREMSSTRAHLUNG EFFECTS ON SPECIFIC IMPULSE IN ELECTROTHERMAL PROPULSION DEVICES

Hassan, H. A.

Journal of the Aerospace Sciences, v. 29, no. 8,
pp. 1005–1006, August 1962

(AI/A, 1962, #61,335)

450. PROPERTIES OF PLASMAS AS THEY PERTAIN TO THERMAL ARC-JETS

Meltzer, J., Chen, C. J., Greco, R. V., McKenna, Q.,
Mitcheltree, G., Price, R., Stoner, W. A.

August 1962

Plasmadyne Corporation, Santa Ana, Calif.

Final Report for February 15, 1961–February 15, 1962,
ASD TDR-62-451, AF 33(616)-8173

AD-292,001

(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

The purpose of this study is to present information which will aid in selecting propellants for use in electrothermal engines. Several potential propellants are examined, including hydrogen, ammonia, helium, lithium hydride, nitrogen, methane, air, argon, and lithium. Important propellant properties and their effect on engine performance and life are

in space are discussed: (1) transfer of a satellite from an initial 300-nm orbit about the Earth to a 20-mi altitude circular orbit about the Moon; (2) satellite network distribution, such as the commercial communication satellite project; (3) final maneuvers when entering the atmosphere of planets; and (4) satellite attitude controls. The application of electrical propulsion engines becomes especially attractive when the power supply forms a part of the payload. (IAA, 1963, A63-10729)

456. EXPERIMENTAL DETERMINATION OF THE HYDROGEN RECOMBINATION CONSTANT

Widawsky, A., Oswalt, L. R., Harp, J. L., Jr. (Propulsion Technology Research Dept., Astro Div., Marquardt Corp., Van Nuys, Calif.)

ARS Journal, v. 32, no. 12, pp. 1927-1929, December 1962

An analytical and experimental investigation is presented of the value of the hydrogen recombination-rate constant at operating conditions applicable to a hydrogen-propelled arc-jet engine. Two techniques for the analysis of the experimental data are used, one of which is an approximate method employing the Bray criterion for incidence of chemical freezing. The second is an exact solution of the nonequilibrium expansion. It is found that the approximate solution gives essentially the same results as the exact solution. In the experimental program, two conical axisymmetric exhaust nozzles are used, each having an expansion area ratio of 40/1, but one having five times the geometric expansion rate of the other. The tests are conducted over a range of inlet total pressures from 0.8 to 2.5 atm, and over a range of inlet total temperatures from 6200 to 7800°R. (IAA, 1962, A63-11560)

457. MATERIALS REQUIREMENTS FOR PLASMA

PROPULSION (Presented at the American Society for Metals Golden Gate Conference, San Francisco, Calif., February 15-17, 1962)

Gates, D. W. (Research Projects Div., George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)

In "Materials Science and Technology for Advanced Applications," pp. 123-125

Marsh, D. R., Editor

Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962

A brief description of one ac and three dc arc-jet engines is given, emphasizing the operation parameters pertinent to the selection of materials. Various propellants and their effects are noted. Some advanced areas of materials technology are reviewed to indicate directions for future research and development. Materials problems not concerned with the engine are mentioned, but concentration is on the electrode and nozzle considerations. Materials discussed include the following: tungsten, molybdenum, graphite, hafnium boride, tantalum carbide, hafnium carbide, boron nitride, tantalum boride, and beryllium oxide. Fifteen references are given. (IAA, 1963, A63-11968)

458. ELECTROTHERMAL PROPULSION—PROBLEMS

AND PROGRESS (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Ghai, M. L. (Plasmajet Systems Div., Space Dynamics Corp., Cincinnati, Ohio)

1962

American Rocket Society, New York, N.Y.

Paper 2348-62

Electrothermal engines have been operated so far at specific impulses up to about 1300 sec with efficiency of 25 to 55%. It has been analytically predicted that the hard to measure "profile loss" (i.e., loss of performance due to boundary layer buildup in the jet), may be as important as some of the other major losses, such as nozzle heat flux and dissociation. Equations are given to compute the order of magnitude of performance loss as well as the boundary-layer thickness in electrothermal propulsion engines having laminar, low density, and very high enthalpy streams. Typical results are shown for 30- and 3-kw engines. A simplified method for computing the boundary-layer thickness and its effect on propellant flow and specific impulse of the engine is presented. (TPA, 1962, N62-15927)

459. ARC JET CHAMBER DESIGN FOR A

MAGNETICALLY SPUN D-C ARC (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Boldman, D. R.

1962

American Rocket Society, New York, N.Y.

Paper 2349-62

A concentric-cylinder type of electrode configuration incorporating a magnetic field is evaluated in order to determine the parameters which dictate clean, stable, and efficient operation. Experimental results indicate the arc potential difference in nitrogen is essentially independent of the 1-7 atm pressure range except for a specific range of operating conditions in which a 26% increase in arc-potential difference is obtained. Highest efficiencies are achieved during the high-potential operating mode; also, stagnation enthalpies approaching 15,000 Btu/lb are obtained under these conditions. Photographs of the arc reveal some of the effects of varying the magnetic field. (IAA, 1962, #62-11825)

460. A CHEMICAL ARC-JET ROCKET FEASIBILITY

STUDY (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Bender, R. W.

1962

American Rocket Society, New York, N.Y.

Paper 2354-62

Chemically-reactive propellants for use in the combined chemical rocket engine and arc jet (the so-called chemical arc-jet rocket engine) are evaluated for the purpose of selecting a propellant for vehicle performance rather than for

uses nitrogen and has an electric input of 30 kw. Thrusts in the range of 0.5 lb are obtained without appreciable electrode consumption. (IAA, 1963, A63-18935)

467. **PROPULSION APPLICATION OF THE MODIFIED PENNING ARC PLASMA EJECTOR** (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Kilpatrick, W. D., Mullins, J. H., Teem, J. M.
AIAA Journal, v. 1, no. 4, pp. 806-813, April 1963

A theoretical and experimental investigation is presented of several critical problems which arise from the adaptation of a modified Penning-type arc to plasma propulsion. The use of a cold-cathode discharge using an alkali metal fuel is considered as an attractive alternative to thermionic discharges, particularly where plasma exhaust velocities are characterized by $2000 < I_{sp} < 4000$ sec. Analyses show that the cathode losses are dependent upon the probability of ionization, secondary electron yield, sputtering, and exhaust efficiency. Particular emphasis is placed upon the problem of ejecting the exhaust plasma that is formed in the arc, first through a divergent solenoidal magnetic field and then into free space. Experimental evidence, using a special cold-cathode plasma generator, confirms the calculations of the critical problems to an order of magnitude. Both experimentally and theoretically, within the limits of the modified Penning plasma generator, the results indicate that, at present, it is inefficient for propulsion and that there is an especially important associated problem of plasma ejection through the magnetic gradient exhaust region. Ten references are included. (IAA, 1963, A63-15875)

468. **SISTEMI DI PROPULSIONE ELETTROTHERMICA (ELECTROTHERMAL PROPULSION SYSTEMS)**
(Presented at the Second International Technical and Scientific Space Congress and Ninth International Electronic, Nuclear, and Teleradiocinematographic Exhibit, Rome, Italy, June 11-24, 1962)
Monti, R. (Aeronautical Institute, University of Naples, Italy)
Missili, v. 5, pp. 79-92, April 1963 (in Italian)

The problems connected with the construction and applications of electrothermal propulsive devices are reviewed. Nozzle behavior is examined in the presence of chemical nonequilibrium phenomena caused by the high temperature and high velocity of the gas propellant. With reference to a linearized analysis which yields information on the design parameters to be considered, proposals are examined for increasing the nonequilibrium efficiency. It is recommended that either the nozzle contour be suitably shaped or an attempt be made to influence the chemical kinetics of the dissociation reaction during propellant expansion inside the nozzle. Twelve references are given. (IAA, 1963, A63-21458)

469. **POWER SOURCE FOR A 1-KW ARC ENGINE TEST CAPSULE** (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)
Boehme, R. J., Cagle, E. H. (George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Ala.)
AIAA Journal, v. 1, no. 5, pp. 1168-1169, May 1963
(Also available as Paper 2351-62, American Rocket Society, New York, N.Y.)

The design of a 1-kw arc-engine power supply for use with the Scout Electric Rocket Test (SERT) program is described. The most significant features of the power supply are the excellent control, stability, increased engine life, and efficiency. Data obtained from actual arc-engine tests are included. The conclusions drawn are based on preliminary analysis of prototype engine and power-supply test runs. Although the feasibility of the system has been demonstrated, the development is not considered complete. (IAA, 1963, A63-17015)

470. **ÉLECTRICITÉ ET PROPULSION SPATIALE (ELECTRIC POWER AND SPACE PROPULSION)**
Gérardin, L. (Compagnie Française Thomson-Houston, Paris, France)
Doc. Air Espace, Service de Documentation et d'Information Technique de l'Aéronautique, Paris, pp. 27-40, May 1963 (in French)

The major characteristics of electric propulsion systems are discussed, and descriptions are given of the basic theories of electrothermal and ion propulsion as well as the present state of their development. Reference is made to the different sources of ions and to the stabilization of heavy material particles for ion propulsion. Present and future ranges of application of electric propulsion, and missions that lend themselves to its use, are also considered. (IAA, 1963, A63-23154)

471. **POSSIBLE EFFECTS OF NONUNIFORM FLOWS ON PERFORMANCE OF ELECTROTHERMAL THRUSTORS**
Jack, J. R., Schaefer, J. W. (Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio)
June 1963
National Aeronautics and Space Administration, Washington, D.C.
NASA TN D-1732
(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

The effects of a nonuniform enthalpy profile on the performance of an electrothermal thrust generator are evaluated analytically. Performance characteristics are presented for uniform specific impulses ranging from 1000 to 2000 seconds, pressures of 0.01 to 100 atmospheres, and engine wall temperatures of 500° and 3000°K. The nonuniform profile changes the uniform specific impulse by 10 percent at most

Co., Evendale, Ohio)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 21-42

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

(Also available as Paper 2347-62, American Rocket Society, New York, N.Y.)

Development work was conducted on a three-phase arc plasma arc-jet engine. The problems associated with the design of this engine were attacked analytically as well as experimentally. Both phases are described, and a comparison between the analytically predicted performances for such an engine and the actual test results is presented. Three areas are covered by the analytical work: (1) thermodynamics of the open cycle of a plasma-arc jet engine; (2) fluid dynamics of the engine nozzle; and (3) heat transfer effects in the engine. The thermodynamic analysis is presented in such a form that, from it, the operating requirements for an ideal plasma arc-jet engine for which minimum performances have been specified can be determined. The fluid dynamic analysis and the heat transfer analysis evaluate the losses which are peculiar to each particular engine design. Instrumentation used for the testing of the engines is described, the degree of accuracy of measured test data is discussed, and the limitation on the instrumentation is objectively assessed. (TPA, 1962, N62-15856)

477. ARC JET ENGINE PERFORMANCE—EXPERIMENT AND THEORY. IV (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

John, R. R., Chen, M. M., Connors, J. F., Megrue, J. F. (Research and Advanced Development Div., Avco Corp., Wilmington, Mass.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 43-68

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

The behavior of arc-jet engines, including engine voltage, current, thrust, and chamber pressure following the initial power input, has been analytically and experimentally determined. Results are presented on the engine thrust and specific impulse following power shutoff. A model is presented for the nozzle flow pattern in an arc-jet engine with spatially nonuniform flow. Preliminary discussions are provided on the performance of a combined arc-engine crossed-field accelerator. Twelve references are given. (IAA, 1963, A63-25929)

478. ARC JET DESIGN (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Masser, P. S. (Masser Engineering Co., Santa Ana, Calif.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 69-77

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

The flow conditions through the cylindrical front electrode of a typical arc jet with radial symmetry are analyzed. The analysis combines the momentum, energy, and continuity equations with Ohm's law and continuity of current to provide a series of equations that can be solved directly on a digital computer. Electrical conductivity can be a function of both the equation of state of the gas and the voltage gradient. A computer solution using simplified gasdynamic properties is presented for the case of 0.01 lb/sec of hydrogen, 1-atm pressure, and 1000-amp current. (IAA, 1963, A63-25930)

479. CHEMICAL NONEQUILIBRIUM EFFECTS IN THERMAL ARC JET PROPULSION (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Mironer, A. (Aracon Labs., Avco Corp., Concord, Mass.),

Macomber, H. (Harvard University, Cambridge, Mass.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 121-146

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

An approximate method for determining the freezing point in an expanding plasma flow is briefly discussed. The analysis shows that the flow is completely frozen in the dissociation-recombination reaction for nozzle throat diameters of less than 10 cm and throat pressures of about 1 atm. Arc-jet engine performance for both equilibrium and frozen flow is evaluated in terms of the frozen-flow and nozzle-expansion efficiencies. (IAA, 1963, A63-25933)

480. MAGNETICALLY DIFFUSED RADIAL ELECTRIC-ARC AIR HEATER EMPLOYING WATER-COOLED COPPER ELECTRODES (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Mayo, R. F., Davis, D. D., Jr. (Langley Research Center, National Aeronautics and Space Administration, Hampton, Va.)

In "Electric Propulsion Development. Progress in Astronautics and Aeronautics. Volume 9," pp. 147-162

Stuhlinger, E., Editor

Academic Press, Inc., New York, N.Y., 1963

A magnetically rotated electric-arc air heater is described in which an intense magnetic field of the order of 10,000 to 25,000 gauss is employed. This field is supplied by a coil that is connected in series with the arc. Experimentation with this heater shows that the presence of an intense magnetic field transverse to the arc results in diffusion of the arc, and that the arc has a positive effective resistance. With the field coil in series with the arc, highly stable arc operation is obtained from a battery power supply. (IAA, 1963, A63-25934)

481. STUDIO SPERIMENTALE DI UN PLASMAGETTO AD ARCO CON STABILIZZAZIONE ELETTRO-MAGNETICA PER IMPIEGHI ASTRONAUTICI

John, R. R., Bennett, S., Cass, L. A., Chen, M. M.,
Connors, J. F. (Research and Advanced Development Div.,
Avco Corp., Wilmington, Mass.)
1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-022, NAS5-600

Analytical and experimental results are presented on the energy addition and loss mechanisms within a 30-kw radiation-cooled hydrogen arc-jet engine. Photographic observations obtained within the arc-engine constrictor section demonstrate the existence of a narrow laminar-like central core flow. The observed core flow diameter (~ 1.5 mm) is in agreement with prediction based on the assumption that the axial mass flux within the central column is negligible. The existence of a nonuniform nozzle throat flow is shown to lead to thrust values larger or smaller than those for uniform nozzle throat flow, depending on the spatial distribution of mass flow and power across the nozzle throat plane. The existence of a core flow mechanism of arc-engine energy transfer indicates that energy can be transferred to the working fluid with a minimum degree of contact between the arc-heated gases and the engine walls. The energy transfer mechanism alleviates the arc-engine material problem to some extent, and offers a rational basis for believing that the arc engine still has a considerable specific-impulse growth potential. Twelve references are given. (IAA, 1963, A63-16669)

**486. NASA RESEARCH ON RESISTANCE-HEATED
HYDROGEN JETS** (Presented at the AIAA Electric
Propulsion Conference, Colorado Springs, Colo.,
March 11-13, 1963)

Jack, J. R., Spisz, E. W. (Lewis Research Center, National
Aeronautics and Space Administration, Cleveland, Ohio)
1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-023

Experimental results are reported for two basically different design approaches to the resistance-heated hydrogen thruster. One thruster employs a tungsten-tube heat exchanger and is water cooled, whereas the other uses a tungsten-wire coil heat exchanger and is radiation cooled. Data are obtained over an input power range of 0 to 38 kw for propellant flow rates of 10^{-3} lb/sec. For the water-cooled tube, heat-exchanger unit at the design power level (30 kw), $I_{sp} = 700$ sec is achieved with an overall thruster efficiency of 36%. Sufficient data and experience have now been obtained on the research unit to design a radiation-cooled thruster for space application with a potential performance of $I_{sp} = 1000$ sec and an efficiency of 75%. For the wire-coil unit with an input power of 15 kw, $I_{sp} = 710$ sec with an efficiency of 73% is attained. This compares to the values of $I_{sp} = 600$ sec and 52% efficiency for the tube heat-exchanger model. The higher efficiency of this device demonstrates the expected improved performance of this design approach,

and indicates the potentially high efficiencies attainable. (IAA, 1963, A63-16667)

487. THE SUBLIMATION OF TUNGSTEN IN HYDROGEN
(Presented at the AIAA Electric Propulsion Conference,
Colorado Springs, Colo., March 11-13, 1963)

Short, G. R., Howard, J. M. (Marquardt Corp., Van Nuys,
Calif.)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-024

The sublimation of tungsten in a hydrogen atmosphere as a function of pressure and temperature was determined. The temperatures used in these experiments were 2800, 3000, and 3200°K and the hydrogen pressure range was from 0.1 to 7600 mm Hg. It was found that sublimation can be suppressed significantly at a given temperature by an increase in hydrogen pressure. The scope of work included sublimation both in a static environment and under flow conditions.

The experimental data are compared with previously published information based on low-pressure inert atmosphere or vacuum experiments. A discussion of the test instrumentation, equipment, and procedures is included. To relate the information on sublimation to practical, contemporary applications, a discussion of the long-term effects of sublimation on the performance of a hypothetical electrothermal engine is presented. (IAA, 1963, A63-16666)

**488. POWER ADAPTER SYSTEMS FOR ELECTRO-
THERMAL ENGINES** (Presented at the AIAA Electric
Propulsion Conference, Colorado Springs, Colo.,
March 11-13, 1963)

Geideman, W. A., Jr. (Plasmadyne Corp., Santa Ana, Calif.)

1963

American Institute of Aeronautics and Astronautics, Inc.,
New York, N.Y.

P63-025

The electrical outputs of all the proposed space powerplants are summarized, and the electrical power requirements of electrothermal arc jets (both ac and dc) and resistojets listed. The power adapter system requirements for each combination of space powerplant and electrothermal engine are described and analyzed. These systems are compared on the basis of overall electrical efficiency and system weight. The possibilities of powerplant changes to optimize the power system are discussed. The various components of the power adapter system—namely, the transformers, stabilization devices, and rectifiers—are discussed in detail as to their effect on the overall weight, efficiency, and reliability of the system. Several different stabilization techniques are noted. The rectification system is considered in detail, with respect to the effects of various factors associated with the

NUCLEAR-ELECTRIC

493. SELECTION OF POWER REQUIREMENTS FOR
NUCLEAR-ELECTRIC SPACECRAFT MISSIONS

Davis, J. P.

May 24, 1961

Jet Propulsion Laboratory, California Institute of
Technology, Pasadena

TR 32-114, NASA CR-51018, NASw-6, NAS 7-100

(Also available through U.S. Dept. of Commerce,
Office of Technical Services, Washington, D.C.)

A Mars orbiter mission is used to illustrate an example of the basic approach. Having selected launch vehicle, payload, and flight time, the distribution of powerplant and propellant weight is discussed. Curves are presented which indicate the minimum power requirement for the mission, the power range which affords maximum powerplant design flexibility, and the powerplant specific weights which must be attained to accomplish the mission. The interplay between mission requirements and powerplant development is indicated. The paper concludes with the indication that a nuclear-electric plant, in the power range of 100 kw(e) propulsion at a specific weight in the range of 35 lb/kw(e), can accomplish a useful Mars orbiter mission in a reasonable flight time, while delivering a useful scientific payload. Data are also presented for two Jupiter missions. (STAR, 1963, N63-21253)

494. A TWO-FLUID MAGNETOHYDRODYNAMIC CYCLE
FOR NUCLEAR-ELECTRIC POWER CONVERSION

Elliot, D. G.

June 30, 1961

Jet Propulsion Laboratory, California Institute of
Technology, Pasadena

TR 32-116

(Also available in *ARS Journal*, v. 32, no. 6,
pp. 924-928, June 1962)

Only a few methods are available for converting nuclear power to electric power without the use of moving mechanical parts. One method heats the working fluid to the plasma state and employs it as the moving conductor in an MHD generator. For a lightweight system in the megawatt range, however, the plasma temperature required is beyond foreseeable reactor technology. To circumvent this limitation, it is proposed that the MHD generator employ a liquid metal as the conductor, the metal being accelerated by the vapor of a second fluid in a two-phase nozzle and extracted by a liquid-gas separator. From available data on such devices, it is estimated that a cycle efficiency of 10% is attainable at a radiator-to-reactor temperature ratio of 0.7. Suitable working fluids for a reactor coolant temperature of 2000°F are potassium vapor and liquid lithium. The estimated specific weight of the two-fluid MHD conversion system is comparable to that of turbine-driven systems. (AI/A, 1961, #4143)

495. THERMOELECTROSTATIC GENERATOR
PROMISES HIGH SPECIFIC POWER

Bean, B. H.

Space/Aeronautics, v. 35, no. 6, pp. 79-80, 82,
85-86, 88, 90, June 1961

A thermoelectrostatic generator is essentially a thin film capacitor alternately heated by solar radiation and cooled by radiant emission. In this article, electrostatic and thermodynamic cycles of such a generator are analyzed to show the interaction of parameters that determine the unit's efficiency. In addition, the problems of dielectrics for a thermostatic generator are discussed, and a relationship is outlined for meaningful comparison of chemical and electric propulsion systems. (EI, 1961)

496. SYSTEMS ENGINEERING OF A NUCLEAR-
ELECTRIC SPACECRAFT

Beale, R. J.

October 31, 1961

Jet Propulsion Laboratory, California Institute of
Technology, Pasadena

TR 32-158

(Also available in *Astronautics*, v. 7, no. 6, pp. 26-30,
June 1962)

This report briefly reviews some of the major integration problems and constraints which must be considered in the design of unmanned nuclear-electric deep-space instrumented scientific probes, and illustrates these considerations with a description of two spacecraft concepts, a 60-kw(e) Venus-capture and a 1-Mw(e) Jupiter-capture spacecraft. In addition, the major hardware development goals which must be accomplished in bringing these designs to realization are discussed. (AI/A, 1961, #4555)

497. PERFORMANCE OF NUCLEAR-ELECTRIC
PROPULSION SYSTEMS IN SPACE EXPLORATION

Speiser, E. W.

December 1961

Jet Propulsion Laboratory, California Institute of
Technology, Pasadena

TR 32-159, NASw-6

Payload capabilities of nuclear-electric spacecraft for interplanetary exploration are analyzed. Results are presented in terms of vehicle terminal mass at its destination as a function of flight time for the mission. The missions which have been studied include probes and orbiters to most of the planets in the solar system, plus solar probes and flights out of the plane of the ecliptic. For a given mission, flight time is determined chiefly by the initial acceleration of the spacecraft, whereas terminal mass is determined chiefly by the specific impulse of the thrust device. Some generalized curves are presented which indicate the initial accelerations required for several missions. The specific impulses required for various ratios of terminal mass to initial mass are shown for the same missions. Once a particular set of mission

The prospects for fusion power, and the role of such units in space propulsion systems are discussed. A method of fusion plasma production employing photoelectric dissociation is described. A conceptual design of a space propulsion system employing fusion power is given, including its probable capability. It is concluded that the expected performance of such a system warrants a considerable developmental effort. (AI/A, 1962, #61,743)

505. METALLURGICAL ASPECTS OF FUTURE SPACE MISSIONS

Johnstone, S. T. M.
Australian Institute of Metals, Journal of the,
v. 7, no. 4, pp. 202-215, November 1962

The probable effects of a range of space environments on space vehicle materials are reviewed, and some proposed methods for the conversion of solar or nuclear energy to electric power for propulsive and auxiliary purposes are discussed. Particular attention is devoted to the nuclear heat transfer rocket and the nuclear electric rocket, including a survey of possible materials for critical applications such as reactor fuel elements, nozzle throats, cryogenic storage, and metal vapor turbine blades. The importance of refractory metals in the future high power systems required to achieve the objective of interplanetary flight is emphasized. Fifty-four references are given. (EI, 1963)

506. NUCLEAR-ELECTRIC-PROPULSION ENERGY CONVERSION OBJECTIVES (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Valentine, P. J.
1962
American Rocket Society, New York, N.Y.
Paper 2437-62

Several aspects of the task of implementing the unmanned exploration of deep space were examined under NASA sponsorship. These included the results of a design study for a turbogenerator, which is suggested as the heart of a possible energy-conversion system suitable for use on a nuclear-electric-propulsion deep-space mission. It is estimated that the thrust motor input power requirement for placing a 45,000-lb spacecraft into a Jupiter capture mission is 1.0 Mw(e). The turbogenerator system described consists of two counter-rotating 600-kw(e) alternators. All bearings are lubricated by liquid cesium. The complete powerplant must operate unattended as a system for periods up to 20,000 hr after orbital startup in the spacecraft. (IAA, 1962, #62-11818)

507. THE ROLE OF ELECTRIC PROPULSION IN FUTURE SPACE PROGRAMS (Presented at the ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, Calif., November 13-18, 1962)

Schwartz, I. R. (National Aeronautics and Space Administration, Washington, D.C.), Stuhlinger, E. (George C. Marshall Space Flight Center, National Aeronautics and

Space Administration, Huntsville, Ala.)
1962
American Rocket Society, New York, N.Y.
Paper 2654-62

An attempt is made to focus the results of research and development efforts on electric propulsion systems through analysis of the payload capabilities of nuclear electric spacecraft. The following major areas of space activity are analyzed: (1) unmanned interplanetary exploration, (2) manned interplanetary exploration, (3) ferry freight for logistic support, and (4) satellite raising and orbital station keeping. Missions to Mars, Venus, Jupiter, Saturn, and Pluto have been examined as well as solar probes and missions out of the plane of the ecliptic. Studies have been made to determine the capabilities of nuclear-electric-powered spacecraft for transferring freight from an Earth orbit to a lunar orbit for logistic support of a manned lunar exploration. Electric rocket payload data are compared with chemical rocket data. (AI/A, 1963, #70,394)

508. CONTROLLED THERMONUCLEAR REACTIONS FOR SPACE APPLICATIONS (Presented at the ARS Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Luce, J. S.
1962
American Rocket Society, New York, N.Y.
Paper 2444-62

Research needed to prove the feasibility of controlled thermonuclear reactions for space propulsion is outlined. Discussed are the ignition of the ^3He -D fusion reaction, the high-energy neutral injection, the production of energetic neutral atoms, the neutral ionization and trapping, the molecular hydrogen arc, and Bremsstrahlung losses. It is concluded that a major breakthrough has been achieved in containing plasmas in magnetic fields which essentially consume no power. (IAA, 1962, #62-11814)

509. DUAL ELECTRIC-NUCLEAR ROCKETS FOR INTERPLANETARY MISSIONS (Presented at the IAS National Summer Meeting, Los Angeles, Calif., June 19-22, 1962)

Levoy, M. (Reaction Motors Div., Thiokol Chemical Corp., Denville, N.J.)
1962
Institute of the Aerospace Sciences, Inc., New York, N.Y.
Paper 62-117

Very large space vehicles will be required for the performance of such difficult space missions as a seven-man exploratory mission to Mars. The gross weights of nuclear rockets in 300-nm initial Earth orbit for relatively fast trips will be on the order of millions of pounds. A substantial reduction in space vehicle gross weight can be effected by the use of a dual electric-nuclear engine described below. Depending on payload requirements and achievable engine

515. FISSION FRAGMENT CONVERSION REACTORS FOR SPACE

Heindl, C. J., Krieve, W. F., Meghreblian, R. V. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena)

Nucleonics, v. 21, no. 4, pp. 80-85, April 1963

A reactor in which fission-fragment kinetic energy is converted directly into electric power offers interesting prospects for space applications. Like the better known thermoelectric and thermionic direct-conversion reactors under development, it would have the advantage of no moving parts. In addition, because the energy-conversion process does not depend on a temperature differential between anode and cathode, the waste-heat radiator can operate at temperatures nearer those of the reactor core and, hence, can be smaller and lighter than in other direct-conversion systems. The basic fission-electric conversion cell has been under investigation at the Jet Propulsion Laboratory for the past few years; it essentially consists of a very thin layer of fissionable material covering the surface of a cylindrical cathode, separated by a vacuum from the anode that acts as a fission-fragment collector. Because each fragment carries about 20 positive charges on the average, and the average kinetic energy is 80 Mev, continued open-circuit operation should lead to a buildup of h-v potential; the h-v source is advantageous in some applications, such as the electrical propulsion of space vehicles. The electrical efficiency, reactor core size, and weight of the system are analyzed as well as in-pile and high-voltage experiments. Future plans for the system are discussed briefly.

516. FUSION PROPULSION SYSTEM REQUIREMENTS FOR AN INTERSTELLAR PROBE

Spencer, D. F.

May 15, 1963

Jet Propulsion Laboratory, California Institute of Technology, Pasadena

TR 32-397, NASA CR-50964, NAS7-100

(Also available through U.S. Dept. of Commerce, Office of Technical Services, Washington, D.C.)

An examination of the engine constraints for a fusion-propelled vehicle indicates that minimum flight times for a probe to a five-light-year star will be approximately 50 yr. The principal restraint on the vehicle is the radiator weight and size necessary to dissipate the heat which enters the chamber walls from the fusion plasma. Theoretically, the confining magnetic field strength is of reasonable magnitude, 2 to 3×10^5 gauss, and the confinement time is approximately 0.1 sec. (STAR, 1963, N63-21324)

517. NUCLEAR POWER FOR SPACE

Kaprielyan, S. P.

Aerospace Management, v. 6, pp. 32-38, May 1963

The major research projects concerning (1) nuclear engines for outer-space propulsion and (2) compact powerplants as

long life sources for electric power are outlined. The genealogy of nuclear engine projects includes: (1) the flightless Kiwi reactor series for basic technology; (2) the Nuclear Engine for Rocket Vehicle Applications (NERVA) to use the Kiwi reactor technology; (3) the Reactor In-Flight Test (RIFT) vehicle for *Saturn C-5*; and (4) the projected Phoebus advanced reactor series (derived from Kiwi), directed to the study of problems of higher reactor powers and proving the limits of power density. Project Rover, the overall program to develop nuclear rocket propulsion, is discussed, including a summary of the Systems for Nuclear Auxiliary Power (SNAP) series. Programs for electric propulsion development include the Space Electric Rocket Test (SERT) series slated for in-flight evaluation of ion engines, and project MECA, the designation for flight-test series, to study the effects of long-term 0-g state on nuclear power units. A brief description of the laboratories at which these various projects are being developed is presented. (IAA, 1963, A63-18029)

518. DUAL ELECTRIC-NUCLEAR ENGINE (Presented at the American Rocket Society Electric Propulsion Conference, Berkeley, Calif., March 14-16, 1962)

Levoy, M. (Non-Chemical Propulsion Section, Reaction Motors Div., Thiokol Chemical Corp., Denville, N.J.)

AIAA Journal, v. 1, no. 6, pp. 1298-1302, June 1963

A dual electric-nuclear rocket system is described which combines a nuclear rocket for high-thrust phases of manned interplanetary space missions with a cluster of electric engines powered by the same reactor for high-specific impulse, low-thrust phases. For a seven-man fast Mars mission, the dual electric-nuclear engine can reduce the space vehicle gross weight in initial Earth orbit to between 40 and 60% of that for an all-nuclear engine. The nuclear reactor is designed to operate in both open-cycle and closed-cycle systems. During open-cycle high-thrust phases, hydrogen propellant is heated as it flows through the reactor core passages and then exhausts through a nozzle to give $I_{sp} \approx 833$ sec. These open-cycle, high-thrust phases are used for orbital escape or orbital capture. In the closed-cycle phases, the reactor, operating at reduced power, heats a circulating fluid that drives a turbo-generator. The generator, in turn, powers a cluster of MHD accelerators, providing low thrust at $I_{sp} = 4,900$ sec. These low-thrust phases are used for shortening trip times in what otherwise would be the coast periods of the nuclear-rocket mission. Thirteen references are given. (IAA, 1963, A63-17951)

519. A STUDY OF NUCLEAR ELECTRIC AND NUCLEAR ROCKET SPACE PROPULSION

Edelbaum, T. N., Cooley, J. L.

June 1963

United Aircraft Corporation, Research Laboratories, East Hartford, Conn.

B-110053-3

The future of nuclear space propulsion is examined by considering the applicability of both solid-core nuclear rockets

summary of the major subsystem weights are presented. (AI/A, 1962, #5616)

524. CONTROLLED FUSION PROPULSION

Luce, J. S. (Research Div., Aerojet-General Nucleonics, Aerojet-General Corp., San Ramon, Calif.)
In "Advanced Propulsion Concepts. Volume 1," Proceedings of the Third Symposium on Advanced Propulsion Concepts, Cincinnati, Ohio, October 2-4, 1962, pp. 343-380
Gordon & Breach Science Publishers, Inc., New York, N.Y., 1963
(Also available as AD-293,495)

Research on controlled fusion with a ^3He -D plasma is described. Methods of plasma confinement, particle injection and trapping, and plasma ignition are discussed, and some possible applications of fusion to space propulsion noted. (IAA, 1963, A63-25821)

525. FUSION PLASMA PROPULSION SYSTEM

Linlor, W. I., Clauser, M. U. (Research Labs., Hughes Aircraft Co., Malibu, Calif.)
In "Advanced Propulsion Concepts Volume 1," Proceedings of the Third Symposium on Advanced Propulsion Concepts, Cincinnati, Ohio, October 2-4, 1962, pp. 381-404
Gordon & Breach Science Publishers, Inc., New York, N.Y., 1963

Methods used in connection with attempts to obtain a stable fusion plasma are described. Three examples of such developments are indicated: high magnetic field superconductivity, lasers coupled with intense photon sources, and cryogenic pumping techniques. Two methods of plasma production employing electric field dissociation and photodissociation are discussed. The possible design of a space propulsion system employing fusion power is noted. Twenty-four references are included. (IAA, 1963, A63-25822)

526. THE ELECTRIC SPACE CRUISER FOR HIGH-ENERGY MISSIONS (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

Beale, R. J., Speiser, E. W., Womack, J. R. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena) 1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-007
(Also available as TR 32-404, June 8, 1963, Jet Propulsion Laboratory, California Institute of Technology, Pasadena)

A brief systems description is presented of a spacecraft to be powered by a 500 kw(e) nuclear turboelectric powerplant, weighing about 14 lb/kw. The vehicle, with a total weight of 20,000 lb, would be orbited by a *Saturn-B* booster chain. A Jupiter-orbiter mission is used as an example. The modes of operation for the spacecraft are reviewed, and a summary of major subsystem weights is shown. Other study

areas explored indicate a typical power profile for the mission, micrometeoroid armor requirements, the effect of nuclear shielding tradeoffs, and the major factors determining the selection of the optimum power level. (IAA, 1963, A63-15470)

527. A RE-EXAMINATION OF GAS-CYCLE NUCLEAR-ELECTRIC SPACE POWERPLANTS (Presented at the AIAA Electric Propulsion Conference, Colorado Springs, Colo., March 11-13, 1963)

Grey, J., Williams, P. M. (Dept. of Aeronautical Engineering, Princeton University, Princeton, N.J.) 1963
American Institute of Aeronautics and Astronautics, Inc., New York, N.Y.
P63-036

The following five types of nuclear space powerplant cycles are compared: (1) a liquid-metal cycle similar to that of the present SNAP-50; (2) a similar cycle, but using in-pile thermionic diodes instead of turbomachinery; (3) a conventional Brayton (gas) cycle; (4) a similar gas cycle, but using in-pile thermionic diodes; and (5) a new "split-radiator gas cycle." Results of these analyses are presented in parametric form, with specific radiator weights given at the 1-Mw level as functions of peak cycle temperature, thermionic cell efficiency, and minimum radiator temperature. The gas cycle using in-pile diodes is strongly favored by the results of the comparison, but mechanical and radiation damage considerations lead to serious contemplation of the split-radiator cycle. In this cycle an inert gas is heated to very high temperatures ($\sim 3300^\circ\text{F}$) in the reactor and is cooled by a radiator, composed of thermionic diode elements, to acceptable turbine inlet temperatures. The balance of the cycle is then similar to a conventional Brayton cycle, with the turbine used only to drive the compressor. Possible cycle variations discussed include regeneration and the use of a conventional turbogenerator to supplement the thermionic powerplant output. Ideal heat transfer is assumed in all cycles. Results of these performance estimates indicate that the gas cycles can no longer be excluded by the liquid-metal cycle for consideration in space nuclear powerplants. Twenty-eight references are given. (IAA, 1963, A63-15991)

528. A NUCLEAR ELECTRIC PROPULSION SYSTEM FOR MANNED INTERPLANETARY MISSIONS (Presented at the 14th International Astronautical Congress, Paris, France, September 25-October 1, 1963)

Gronich, A., Hallet, R. W., Jr., Miller, P. W. (Missile and Space Systems Div., Douglas Aircraft Co., Inc., Santa Monica, Calif.) 1963
International Astronautical Federation, Paris, France
IAF Paper

A space powerplant for an Earth-orbit-to-Mars-orbit-to-Earth-return manned space flight is discussed. A parametric

ADDENDA

GENERAL

530. RICERCHE SPERIMENTALI SULLA PROPULSIONE ELETTRICA PER IMPIEGHI ASTRONAUTICI PRESSO LA SCUOLA DI INGEGNERIA AERONAUTICA DEL POLITECNICO DI TORINO (Presented at the 17th Congresso Nazionale di Aerotecnica, Torino, Italy, September 27-30, 1961)
Robotti, A. C., Oggero, M.
L'Aerotecnica, v. 41, pp. 263-273, October 1961 (in Italian)

Electrical propulsion systems for space vehicles have been investigated experimentally. The principles of the three main types of such systems (arc-jet, ion, and MGD devices) are reviewed briefly, and various experimental studies of arc and plasma jets are described, particular attention being given to the stabilization of an arc by means of a magnetic field. The experimental devices are illustrated by cross-sectional drawings, and photographs of the arcs and graphs of their characteristics are presented. Twenty-nine references are given. (IAA, 1962, #62-5156)

531. MISSILE AND SPACE ELECTRONICS—PROPULSION AND POWER GENERATION
Mason, J. F., Wolff, M. F.
Electronics, v. 34, pp. 105-107, November 17, 1961

The current status of, and research being performed in, the areas of propulsion and power generation for missiles and space vehicles are surveyed. Research in various advanced propulsion methods is noted, and attention is given to solar, nuclear, and chemical power sources. (IAA, 1962, #62-817)

532. ENERGIE—SCHLÜSSEL ZUM WELTRAUM
Geisenheyner, S.
Flug-Revue, pp. 18-19, 36, December 1961 (in German)

A survey of advanced energy-conversion techniques for space power systems is presented and some developments in ion engines, plasma engines, solar and fuel cells, magneto-hydrodynamic generators, and thermoelectric and thermionic converters are noted. (IAA, 1962, #62-6185)

533. PROPULSION SYSTEMS FOR SPACE TRAVEL
(Presented at the SAE National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., October 9-13, 1961)
Boden, R. H.
1961
Society of Automotive Engineers, Inc., New York, N.Y.
Paper 419D

A method is presented by which lowest cost engine systems to achieve successful space missions with a multistage vehicle can be established and compared. The components considered

in the analysis are the propellants, the propellant tank structures, and the engines. Each of the engine systems studied has an area of application in which the costs are minimal.

The LOX/kerosene engines appear best for missions requiring characteristic velocities below 20,000 ft/sec. The two-stage LOX/hydrogen engine has a favorable application in missions requiring a characteristic velocity of approximately 30,000 ft/sec. The nuclear and chemical-electric systems are competitive for all missions requiring a characteristic velocity between 40,000 and 60,000 ft/sec. Above 60,000 ft/sec, the electrostatic ion engine is superior to all other systems considered. Suggestions are made to reduce the costs of all the systems, and the effects of engine reliability on total costs are emphasized. In general, it is shown that a significant difference exists between the design parameters of a minimum cost system and those of a maximum payload system. Sixteen references are included. (IAA, 1962, #62-1846). (See also Entry #145)

534. CONSIDERATION OF IN-SPACE TESTING OF ELECTRICAL PROPULSION (Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)
Reder, M. C., Sunderland, R. J.
1961
American Rocket Society, New York, N.Y.
Paper 2181-61

The need for in-space testing of electric propulsion is discussed emphasizing the requirements of propulsion-system development, as opposed to investigations concerned primarily with the characterization of physical phenomena basic to the operation of the accelerator. Generalized flight-test objectives are presented along with a discussion of thrust measurement and engine diagnostic techniques from both qualitative and quantitative points of view. In-space test-system concepts are defined, classified, and initially rated, or ordered on the basis of currently available flight equipment. (IAA, 1962, #62-11120)

535. RASSEGNA SUI PROPULSORI SATELLITARI E SPAZIALI
Partel, G.
Rivista Aeronautica, v. 38, pp. 549-593, April 1962
(in Italian)

Various low-thrust propulsion systems which can be used in space operations for orbital launchings are surveyed. The survey covers: (1) general characteristics of electric propulsion systems; (2) electric energy generators, including chemical batteries and other sources of electric energy, as well as

ELECTROSTATIC

542. STADIUL APLICĂRII ENERGIEI ATOMICE LA MOTOARE LE CU REACTIE

Cirdu, M.

Revista Transporturilor, v. 8, pp. 28-34, January 1961 (in Rumanian)

The application of atomic energy to the propulsion of aerospace vehicles is discussed. Power obtained from different types of high-temperature nuclear reactors, constructed to investigate the problems involved, is noted. Thermodynamic problems associated with nuclear heat-transfer rockets are discussed in some detail. The problem of radiation shielding from alpha and beta particles and, especially, gamma rays and neutrons, and the efficacy of different shielding materials is considered. The results of experimental studies of high-power reactors are briefly discussed. Finally, research in the field of ionic propulsion is noted. (IAA, 1962, #62-819)

543. BASIC DATA ON SURFACE IONIZATION AND IMPLICATIONS FOR ION GENERATION IN CESIUM ION ROCKETS (Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)

Dalins, I.

1961

American Rocket Society, New York, N.Y.

Paper 2065-61

Surface ionization is discussed as applied to ion generation cesium-ion rockets. The value of the work function for a tungsten surface is assessed, and the importance of the heterogeneity of the surface is demonstrated by considering the details involved in the atomic processes basic to surface ionization. Curves showing the potential energy of the system vs both atom-to-surface and ion-to-surface distances are presented. An investigation is made of the problem of the real distances between the adsorbed atom and the surface, and two methods for the determination of this distance are described. Based on the corresponding values for other metal surfaces, the adsorption energy for tungsten is calculated, and the results are tabulated. The problems of surface contamination in porous-ionizer operation, arising either from impurities or from a brazed joint between the ionizer and the cesium plenum, are discussed. Thirty-three references are given. (IAA, 1962, #62-11122)

544. ADVANCED ION BEAM DIAGNOSTIC TECHNIQUES

(Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)

Sellen, J. M., Jr., Forbes, S. G., Kemp, R. F., Shelton, H., Slattery, J. C.

1961

American Rocket Society, New York, N.Y.

Paper 2067-61

A series of experiments for the diagnosis of a neutralized, high-aspect ratio cesium ion beam is described. Attention is focused on the more detailed interior structure of the plasma, developing new methods in the diagnosis of such a plasma, and directing an additional emphasis upon the behavior of the electron component in the plasma. Experiments conducted in three different experimental arrays, each possessing its own instrumentation, diagnostic tools, and ion and electron sources, are described. A variety of neutralizer configurations is also described from this series of experiments. The relative effectiveness of each neutralizer may be indicated by the "perveance" between the neutralizer and the plasma. The measurements in the ion beam demonstrate the point-by-point neutrality of the ion-electron plasma, which follows from the absence of curvature in the measured potentials in the beam. The kinetic energies of the electrons in the plasma are found to be several volts for the hot-wire neutralized beams and approximately 10 v for the button-neutralized beams. Experiments conducted to determine if the observed neutralization of the beam is the result of a relatively slow axial velocity of the neutralizing electrons are examined. Under arrangements of potential contours in the plasma similar to the potentials existing in a neutralized beam, streaming velocities of electrons along the axis were measured. The electron motion was found to be such that a substantial fraction of the electron velocity is along the axis of the ion beam.

A numerical analysis of potentials in an ion-electron ensemble is also presented. The model adapted for the analysis assumes the electrons to be elastically random at a central scattering plane in a slab of positive charge. The results indicate that a thorough and effective neutralization of the beam is achieved under conditions similar to those encountered in the vehicular environment. Fifteen references are included. (IAA, 1962, #62-7233)

545. CHARGED PARTICLE DYNAMICS AND ELECTROSTATIC POTENTIAL GRADIENTS IN A NEUTRAL PLASMA (Presented at the ARS Space Flight Report to the Nation, New York, N.Y., October 9-15, 1961)

Davis, J. W., Walch, A. P., Meyerand, R. G., Jr., Salz, F.

1961

American Rocket Society, New York, N.Y.

Paper 2070-61

An analytical and experimental determination of the dynamics of charged particles in a one-dimensional nonuniform plasma, using an oscillating-electron ion engine, is discussed. Specifically, the nature of the momentum exchange between ions and electrons is investigated to study the mechanism by which the reaction force caused by ion acceleration is transmitted to the engine. It is shown that, in the presence of a potential gradient in the plasma, the condition of space-charge neutrality requires a local momentum balance between ions and electrons. This result is used to show that the reaction force of ions discharged from the ion engine is

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